CHARACTERIZING THE FISH COMMUNITY IN TURBID ALASKAN RIVERS TO ASSESS POTENTIAL INTERACTIONS WITH HYDROKINETIC DEVICES

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Abstract

The Yukon and Tanana rivers are two large, glacially turbid rivers in Alaska, where hydrokinetic projects are being explored for feasibility of electricity production. Downstream migration behavior of fishes in these rivers is poorly understood; as a result, the potential impacts of hydrokinetic devices, which will be placed in the deepest and fastest part of the river, on fishes are unknown. Downstream migrating fishes were sampled during the ice-free season along the river margins of the Yukon River in 2010 and the river margins and mid-channel of the Tanana River in 2011. Results suggest that the river margins in the Yukon and Tanana rivers are primarily utilized by resident freshwater species, the mid-channel is utilized by Pacific salmon (*Oncorhynchus* spp.) smolts, and only chum salmon (*Oncorhynchus keta*) smolts utilize both of these areas. Some species exhibited distinct peaks and trends in downstream migration timing including longnose suckers (*Catostomus catostomus*), whitefishes (*Coregonine*), Arctic grayling (*Thymallus arcticus*), lake chub (*Couesius plumbeus*), Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), and chum salmon. As a result of these fishes' downstream migration behavior, hydrokinetic devices installed in surface waters of the middle of the river channel will have the most potential interactions with Pacific salmon smolts during their downstream migration to the ocean from May through July.

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Introduction

Background

Area-specific life-history requirements vary among and within fish species, and typically involve distinct spawning, feeding, and refuge habitats (Lucas and Baras, 2001; Melnychuk *et al*., 2010). Movement among habitats is thought to maximize survival and ultimately increase fitness of individual fishes (Lucas and Baras, 2001). Because these habitats may be geographically separated, fishes undertake movements among these habitats to fulfill their life-history requirements. One such movement critical in increasing the fitness of many fishes is that exhibited by juvenile and larval fishes as they move from natal areas to feeding or refuge areas, which may involve downstream movement in rivers. For these juvenile and larval fishes moving downstream in rivers, most movements are considered to be part of a migration.

Migrations for freshwater fishes have been defined as movements between two or more separate habitats, occur with regular periodicity within the individual's lifetime, and involve a directed movement at some stage of a life cycle by a large fraction of the population (Northcote, 1997). These migrations can be both spatially variable, ranging from a few meters to thousands of kilometers, and temporally variable, ranging from daily to annual (McKeown, 1984). Temporal and spatial characteristics of fish migrations are frequently studied to determine how migration increases a fish's fitness because arriving in a habitat with favorable environmental conditions increases their chance of survival (Achord *et al*., 2007; Chittenden *et al*., 2010; Spence and Hall, 2010).

Spatial and temporal patterns of these downstream migrations by juvenile and larval fishes are often species-specific and variable among river systems (Achord *et al*., 2007). For example, in the Columbia River, age-1 Chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) smolts showed higher relative abundances on the bottom of the mid-channel, whereas age-0 Chinook salmon showed higher relative abundances in nearshore areas (Dauble *et al*., 1989). In contrast, in the Fraser River, age-0 chum salmon (*O. keta*) smolts showed higher relative abundances in the top of the mid-channel (Todd, 1966). It is believed that temporal patterns in downstream migrations by juvenile and larval fishes may be strongly influenced by a variety of factors, such as light, water temperature, hydrology, water quality, food availability, and stimuli interactions (Lucas and Baras, 2001). For example, downstream migration timing by Chinook salmon in the Snake River basin varies as much as three weeks both between years and between streams, and was strongly related to temperature and discharge (Achord *et al*., 2007).

Understanding species- and river system-specific temporal and spatial patterns in downstream migration is becoming increasingly important as human development continues to affect aquatic ecosystems. One example of such development is hydrokinetic devices, which do not divert or impound water, but do use kinetic energy from flowing water to turn a turbine to generate electricity. Feasibility and development projects for hydrokinetic devices are being conducted for some rural communities in Alaska to reduce some of the energy demand on diesel generators (Seitz *et al*., 2011). One of these projects was located in Eagle, AK, (Figure 1) on the Yukon River where a

25-kW in-river hydrokinetic turbine was installed in summer 2010. The turbine, suspended from a pontoon barge in the river mid-channel, had a cross section of 2.4 m in depth, 4.9 m in width, was positioned approximately 0.3 m below the river surface, and spun at a maximum of 22 revolutions per minute. Another project is actively being developed to install a hydrokinetic turbine in the Tanana River near Nenana, AK (Figure 1; Seitz *et al.*, 2011).

Impacts of hydrokinetic turbines on fishes are poorly understood, especially in large, turbid systems like the Yukon and Tanana rivers, both of which are glacially influenced (Seitz *et al.*, 2011). However, traditional hydroelectric turbines and their effect on fishes have been well documented (Cada, 1990; Whitney *et al.*, 1997, Coutant and Whitney, 2000). The mechanisms that cause injury in hydroelectric turbines are pressure changes, cavitation, shear stress, turbulence, blade strike, and grinding (Cada, 2001). Mortality rates for juvenile fish passing through hydroelectric turbines vary depending turbine design, but can range from 5% for the most fish-friendly turbine to 30% (Cada, 2001). Because several engineering aspects of hydrokinetic turbines are fundamentally different than those of conventional hydroelectric turbines, it is necessary to conduct further studies on effects of hydrokinetic turbines on fishes. Preliminary investigations indicate salmonids large enough (> 120 mm) to maneuver in swift currents avoid spinning hydrokinetic turbines in a laboratory flume, resulting in survival rates > 99% (EPRI, 2011), while non-salmonid larval fishes (< 25 mm) with lesser swimming ability typically had lower survival rates as they were unable to avoid turbine blades (Schweizer *et al.*, 2012). In a natural environment, in order for any effects to occur, there must first be an interaction between the hydrokinetic device and fish. To assess the potential of this interaction in turbid glacial river systems such as the Yukon and Tanana rivers, it is necessary to understand the species composition and relative abundance of the fish community and the spatial and temporal patterns of distribution of fishes in the river channel.

Yukon and Tanana River fishes

Nineteen fish species have been documented in the upper Yukon River near the Alaska/Canada border (Bradford *et al.*, 2008), while seventeen fish species have been documented in the Tanana River. Chinook salmon, summer and fall chum salmon, and coho salmon (*Oncorhynchus kisutch*) all occur in the Tanana River (Seitz *et al.*, 2011), while only Chinook salmon and fall chum salmon are found in the upper Yukon River (Bradford *et al.*, 2008).

Chinook salmon are exclusively stream-type in both the upper Yukon and Tanana rivers. In the upper Yukon River, age-0 Chinook salmon emigrate from their natal rivers, migrate down river as fry in late-June (Bradford *et al.*, 2008), and rear in small non-natal streams (Daum and Flannery, 2011). This behavior of non-natal stream rearing has not been documented in the Tanana River, though it has not been specifically looked for. After overwintering, most Chinook salmon then out-migrate to the ocean as age-1 smolts (Beacham *et al.*, 1989; Evenson, 2002) during May and June (Peterson, 1997; Lambert, 1998; Bradford *et al.*, 2008). In contrast, most coho salmon found in the Tanana River have a longer freshwater residency and migrate downstream to the ocean as age-2 smolts

(Pearse, 1974; Raymond, 1986) during April and May (Parker, 1991; Hemming and Morris, 1999).

Chum salmon migrate almost immediately to the ocean as age-0 smolts after emergence from the gravel, without spending rearing time in freshwater (Bradford *et al.*, 2008). Timing of this migration in the upper Yukon and Tanana rivers occurs anytime from early April through June (Francisco, 1977; Hemming and Morris, 1999; Durst, 2001; Bradford *et al.*, 2008), but varies between years based on timing of peak flows (Buklis and Barton, 1984). It is hypothesized that juvenile chum salmon reside in their natal streams until the first high water event, at which time they begin their outmigration (Buklis and Barton, 1984).

Six coregonine species have been documented in the upper Yukon and Tanana rivers. Inconnu (*Stenodus leucichthys*), round whitefish (*Prosopium cylindraceum*), humpback whitefish (*Coregonus pidschian*), and broad whitefish (*C. nasus*) all occur in both river systems, while the least cisco (*C. sardinella*) has been documented in the Tanana River and the Bering cisco (*C. laurettae*) has been documented in the upper Yukon River (Brown *et al.*, 2007; Seitz *et al.*, 2011). Coregonine fishes can exhibit a wide variety of life-history traits including both freshwater resident and amphidromous behavior (migration between freshwater and saltwater not related to breeding, but occurs regularly at some other stage of the life cycle), but only the Bering cisco appears to be amphidromous in the upper Yukon River (Brown *et al.*, 2007). Age-0 coregonines migrate to downriver feeding and rearing locations in the summer where they remain until reaching sexual maturity (Brown *et al.*, 2002), but the specific timing of this downstream migration has not been documented in the Tanana River. In the upper Yukon River, relatively large abundances of downstream migrating age-0 coregonines occur, but the peaks in migration timing are variable among species and years (Bradford *et al*., 2008).

Arctic grayling (*Thymallus arcticus*) occur throughout the tributaries of the Yukon and Tanana rivers and often display extensive migrations between spawning, overwintering, and feeding areas, depending on age and time of year (West *et al*., 1992; Seitz *et al*., 2011). Juvenile Arctic grayling are known to follow the adults during their migration to and from spawning locations, which probably serves as a mechanism for imprinting on migration routes (Tack, 1980). During the summer months, juveniles tend to inhabit lower ends of clearwater tributaries while larger adults inhabit the headwaters (Seitz *et al*., 2011). During the fall, Arctic grayling begin their downriver migration to overwintering locations, which consist of large runoff rivers, lakes, and springs (Tack, 1980), and may involve use of the Yukon and Tanana rivers mainstem.

In addition to salmonids, a variety of freshwater resident species occurs in the Yukon and Tanana rivers. Burbot (*Lota lota*) are a benthic, piscivorous fish whose distribution ranges widely across Alaska where they occur in a variety of lakes and rivers in the Yukon River drainage (McPhail and Paragamian, 2000). Northern pike (*Esox lucius*) are a top-level predator and are typically found in slow-moving water with aquatic vegetation (Muhlfeld *et al*., 2008). Lake chub (*Couesius plumbeus)*, longnose sucker (*Catostomus catostomus)*, and slimy sculpin (*Cottus cognatus)* are widely abundant resident species in the Yukon and Tanana River drainages and have been found to be the most abundant species in mainstem river margins and tributary habitats (Mecum, 1984; Ott *et al.*, 1998; Bradford *et al.*, 2008).

Two species of lampreys in the Yukon River drainage exhibit distinct life-history strategies. The Arctic lamprey (*Lethenteron camtschaticum*) is an anadromous parasitic lamprey that can be found throughout the Yukon and Tanana rivers (Mecklenberg *et al.*, 2002). The Alaskan brook lamprey (*Lethenteron alaskense*) is strictly freshwater and non-parasitic, and has been documented in a few tributaries of the Tanana River (Vladykov and Knott, 1978; Mecklenberg *et al.*, 2002). Larval lampreys of both species, called ammocoetes, burrow in soft substrates where they filter feed on organic detritus for a few years (Sutton and Bowen, 1994). After the ammocoete stage, Arctic lamprey migrate to the ocean and metamorphose into juveniles where they become parasitic, while Alaskan brook lamprey metamorphose into adults and remain in freshwater (T. Sutton, UAF, personal communication). The Arctic lamprey ammocoete downstream migration has been documented in the Russian Far East as occurring in July and August, and is almost strictly nocturnal and strongly correlated with high discharge events (Kirillova *et al.*, 2011). It is possible that the Arctic lamprey and Alaskan brook lamprey are not genetically distinct species, but rather the same species exhibiting two different life-history strategies (Kucheryavyi *et al.* 2007; T. Sutton, UAF, personal communication).

Although a few studies have described the juvenile and larval fish community in parts of the Tanana River (Mecum, 1984; Ott *et al.*, 1998; Hemming and Morris, 1999; Durst, 2001) and upper Yukon River (Bradford *et al.*, 2008), there have not been comprehensive studies describing the temporal and spatial patterns of downstream migrating juvenile and larval fishes at the potential turbine locations in the Tanana River at Nenana, AK, or Yukon River at Eagle, AK. Additionally, very few studies have attempted sampling of the mid-channel in large U.S. rivers (Mains and Smith, 1964; Todd, 1966; Tyler, 1979; Dauble *et al.*, 1989), let alone a turbid glacial river in Alaska (Gissberg and Benning, 1965).

Because juvenile and larval fishes are small and relatively weak swimmers, they may use the highest velocity area of the river channel to conserve energy during downstream migration or be swept into the mid-channel by hydrodynamic forces (Wolter and Sukhodolov, 2008). This is exactly the location where hydrokinetic devices are deployed; therefore, the goal of this study was to provide baseline information about the juvenile and larval fish downstream migration in the mainstem of the Yukon and Tanana rivers to understand spatial and temporal patterns so times of potential interactions between juvenile and larval fishes and a hydrokinetic turbine could be determined. To achieve this goal, the study objectives were to: 1) characterize the juvenile and larval fish communities in the mainstem of the Yukon and Tanana rivers, including species composition and relative abundance; and 2) characterize the spatial and temporal patterns of the downstream juvenile and larval fish migration and determine environmental associations with migration. To accomplish these objectives, downstream migrating juvenile and larval fishes were sampled in the river margins of the Yukon River near Eagle, AK and the river margins and mid-channel of the Tanana River near Nenana, AK. In addition to fish sampling, a suite of environmental variables was collected throughout the sampling season to explore possible associations of these environmental variables with temporal patterns of the downstream migrating juvenile and larval fish. Results from this study provide information about which species/taxa have the most potential for interactions with a hydrokinetic device and when those potential interactions are most likely to occur.

Methods

Study area

The Yukon River is the fourth largest river drainage in North America, covering approximately 860,000 km^2. It flows 3,200 km from its origin in British Columbia through the Yukon Territory and Alaska before ending in the Bering Sea (Beacham *et al.*, 1989) (Figure 1). A series of large lakes make up the headwaters of the Yukon River and turbidity below these lakes is relatively low during the open-water season (Bradford *et al.*, 2008). About 120 km upstream of Dawson, YT, the White River, which is a glacial tributary originating in the Wrangell-St. Elias Mountains, flows into the Yukon River contributing the majority of the high glacial sediment load in the Yukon River for the summer months (Brabets *et al.*, 2000; Bradford *et al.*, 2008). Sampling of the Yukon River occurred near Eagle, AK, located approximately 160 km downstream of Dawson, YT.

The Tanana River is the largest tributary to the Yukon River, contributing about 20% of the total flow of the Yukon River (Brown *et al.*, 2011), with the drainage covering approximately 115,250 km^2 (Figure 1). It is formed at the confluence of the Chisana and Nabesna rivers, which both originate from the heavily glaciated Wrangell-

St. Elias Mountains (Brabets *et al*., 2000). The Tanana River flows 1,000 km from its headwaters to the confluence of the Yukon River (Borba, 2007) and is another large contributor to the glacial sediment in the Yukon River (Brabets *et al*., 2000). Sampling of the Tanana River occurred near Nenana, AK, located approximately 260 km upstream of the confluence with the Yukon River (Seitz *et al*., 2011).

<u>Fish sampling</u>

Fish sampling was conducted in two distinct river habitats: the river margins and the river mid-channel. River margin habitats were characterized by water velocity less than 0.75 $m \cdot s^{-1}$, water depth less than 1.3 m, and within 30 m of the shoreline. Mid-channel habitats were characterized by water velocity greater than 1.2 $m \cdot s^{-1}$, water depth greater than 6 m, and not within 30 m of the shoreline. Sampling of the river margins was accomplished using fyke nets with 1.2-m x 1.2-m frames, dual 9.1-m wings, and 1.27-cm mesh at locations on each river bank in the Yukon and Tanana rivers, as well as at an island in the Yukon River (Figure 2). To modify the gear to fish in the strong current of the Yukon and Tanana rivers without allowing fish to bypass the net, 4.6 m of heavy chain was attached to the lead line of each wing to keep the lead line on the river bottom and buoys were attached to the float line of the offshore wing to keep the float line near the river surface. The nearshore wing was attached to a piece of iron rebar that was driven into the river bed, and the far wing was attached to a 13.6-kg anchor placed on the river bed. At the downstream end of the fyke net was a 0.6-m x 0.6-m x 1.2-m live box with 3-mm mesh that provided the captured fish refuge from the strong river currents.

Sampling of the mid-channel in the Tanana River was accomplished using an incline plane trap attached to a mooring buoy, near the deepest, fastest portion of the river. The inclined plane trap consisted of two major sections: the trap and the live box (Todd, 1994). The trap, composed of an incline plane supported by a frame, had a front opening 1.1-m deep by 1.5-m wide, with an overall length of 2.4 m. The incline plane was composed of v-shaped corrugated aluminum perforated with 8-mm diameter holes (Todd, 1994). When the inclined plane was lowered into the current, the top 1.1 m of the water column was strained through the incline plane and downstream migrant fishes were swept up the incline plane and deposited into a protected, solid-sided and floored live box 1.2-m long, 0.9-m wide, and 0.6-m deep (Todd, 1994).

Sampling of river margins in the Yukon River began on 28 May 2010, continued through 22 September 2010, and was conducted in the morning, afternoon, and evening by concurrently deploying fyke nets at two adjacent sites. Out of consideration for local residents, early morning sets (04:00–07:00) and late night sets (22:00–02:00) were only made twice a week to minimize boat motor sound disturbance. Sampling of river margins in the Tanana River began on 12 May 2011, continued through 28 August 2011, and was conducted by concurrently deploying fyke nets at both river margin locations. Sampling times were evenly stratified over a 24 hour period, as sampling did not occur near local residents so boat motor sound disturbance was not an issue. The target duration for fyke net sets was one hour in the Yukon River in order to minimize unintended sampling mortality. This time was reduced to 30 minutes in the Tanana River to allow for mid-channel sampling preparation and execution, which was very time consuming. The sampling goal for both rivers was six fyke net sets per day.

Sampling of the mid-channel with the incline plane trap in the Tanana River began 20 May 2011, continued through 18 August 2011, and was conducted in conjunction with both set fyke nets. River debris collected in the incline plane trap reduces efficiency and increases fish mortality; as a result, the target sampling duration was limited to one hour per set, and the target number of sets per day was three.

All captured fish were visually identified to the lowest taxonomic level possible, measured to the nearest mm of fork length or total length (burbot, Arctic lamprey, Alaskan brook lamprey, and slimy sculpin), and released alive. Because of difficulty in identifying different species in the genus *Coregonus* and *Prosopium*, all were grouped into a general whitefishes category. Additionally, larval Arctic lamprey and Alaskan brook lamprey are morphologically and genetically indistinguishable, so all larval lamprey were grouped into a *Lethenteron* spp. category while adult lamprey were identified to species. In the Tanana River, because of conflicting literature describing external features for distinguishing Chinook salmon and coho salmon, both species were grouped into a Chinook/coho salmon category (Dahlberg and Phinney, 1967).

All sampling was conducted under the Alaska Department of Fish and Game Fish Resource Permits SF2010-110 in the Yukon River and SF2011-145 in the Tanana River and the University of Alaska Fairbanks Institutional Animal Care and Use Committee assurance 158953.

Environmental variables

The water temperature was measured to the nearest 0.1°C with a Yellow Springs Instrument (YSI) 550A in the Yukon River and a YSI 85 in the Tanana River. A Debris Index (DI) was determined by visualizing a transect across the river, and counting the number of individual pieces of woody debris crossing that transect in a five minute period. Additionally, water depth (m) at the frame, distance between the two wings (m), and water velocity ($m \cdot s^{-1}$) at the frame was measured at 60% of depth from bottom with a General Oceanics 2030R flow meter in the Yukon River and a Marsh McBirney Flo-Mate 2000 in the Tanana River for each fyke net set. Water velocity ($m \cdot s^{-1}$) was measured with a Marsh McBirney Flo-Mate 2000 in front of the incline plane trap 0.64 m beneath the water surface for each set. Turbidity (cm) was measured daily in the middle of the river channel using a secchi disk. River discharge ($m^3 \cdot s^{-1}$) data were obtained from the US Geological Survey gauging station in Eagle, AK (http://waterdata.usgs.gov/nwis/uv?15356000) and Nenana, AK (http://waterdata.usgs.gov/ak/nwis/uv?site_no=15515500). An attempt was made to measure each environmental variable for the duration of the study, but equipment availability prevented measurement during some time periods.

Data analysis

Catch per unit effort (CPUE) of each fish species/taxa was calculated by dividing catch in each set by the volume of water sampled (water depth (m) x width of net (m) x water velocity ($m \cdot s^{-1}$) x 1,000). These CPUE ($\#fish \cdot 1{,}000\ m^{-3}$) values were used to compare relative abundances among species/taxa.

Generalized additive models (GAM) were used to describe temporal patterns in catches and to determine associations of catches with environmental variables. Generalized additive models are non-parametric generalizations of generalized linear models and use additive instead of linear predictors (Hastie and Tibshirani, 1990; Venables and Dichmont, 2004). The general formula of a GAM (equation 1) can be written as:

$$g(\mu)=\beta_o+\sum_{i=1}^{p} f_i(X_i), \tag{1}$$

where g is the link function, μ is the expectation of observations, β_o is the intercept, $X_1,\ldots,X_p$ are independent variables, and f_i is the non-parametric or smooth function. Three variations of this model were used to describe temporal patterns in catches on both a seasonal scale (equation 2) and daily scale, which included date and time of day as an interaction term (equation 3), and to determine associations of catches with environmental variables (equation 4).

$$\log\left(\#\frac{\text{fish}}{\text{set}}\right)=\beta_o+f_1(\text{Date})+\log(\text{volume})+\varepsilon, \tag{2}$$

$$\log\left(\#\frac{\text{fish}}{\text{set}}\right)=\beta_o+f_2(\text{Date,Time of Day})+\log(\text{volume})+\varepsilon, \tag{3}$$

$$\log\left(\#\frac{\text{fish}}{\text{set}}\right)=\beta_o+f_1(\text{Date})+f_3(\text{Temp})+f_4(\text{DI})+ f_5(\text{Turbidity})+\log(\text{volume})+\varepsilon, \tag{4}$$

where β_o = the intercept, volume = water volume sampled, Temp = water temperature, DI = Debris Index, $f_{1,2,3,4,5}$ = the smoother functions and ε = error.

All GAM models were only applied to species/taxa where sample size was > 150 fish because catch data for species/taxa with a sample size < 150 fish contained too many zeros to elucidate any patterns. To avoid over-fitting of the GAM models as well as masking true patterns in catches, upper bounds for degrees of freedom (*df*) were set for each smoother function (15 *df* for f_1 (equations 2 and 4), 25 *df* for f_2 (equation 3), and 3 *df* for $f_{3,4,5}$ (equation 4)). Additionally, log(water volume sampled) was included as an offset in each equation to account for different volumes of water sampled by each sampling device. Because the catch data was highly over-dispersed and right skewed as a result of very low or very high catches, a negative binominal distribution was specified in each equation, using the performance iteration function to estimate the over-dispersion parameter. Statistical analysis and plotting were carried out using the R computer language and packages, version 2.11.1 (http://www.r-project.org).

Results from equation (2) were used to produce smother (non-linear) trend lines ± 95% confidence intervals (CI) of predicted number of fish per set, given the mean volume of water sampled, of each species/taxa over the sampling season. Species/taxa were determined to exhibit seasonal temporal patterns if the slope for the date-smoothing parameter (equation 2) was significantly different from zero, assessed at the $\alpha = 0.05$ level. These temporal patterns in catches were either described as having peaks or increasing/decreasing trends, which was determined by examining the smoother trend line ± 95% CI. Peaks were qualitatively defined as a period of increasing catches, immediately followed by decreased catches. Increasing and decreasing trends occurred when the slope of the smoother trend line was either positive or negative.

Potential differences in night and day catches were explored by comparing the Akaike Information Criterion (AIC) (Akaike, 1973) values between equation (2) and equation (3). If equation (3) had an AIC less than that of equation (2), and the ΔAIC was greater than 2 (Burnham *et al.*, 2011), daily patterns were deemed to exist. In these cases, contour plots were created and qualitatively assessed by examining contour lines, which represented deviations from the overall mean on the log-scale (anomalies), for periods of high and low catches.

To explore associations of catches with three environmental variables (water temperature, the Debris Index, and turbidity), an all subsets regression approach was used on equation (4) and the most parsimonious nested model was chosen based on lowest AIC. Because turbidity was not measured for the first month of sampling in the Yukon River, additional models were created that excluded the first month of Yukon River fish sampling to examine possible association between turbidity and catches. Turbidity was not associated with catches of any species/taxa in the Yukon River, therefore it was not considered in model selection, which included only water temperature and the debris index. All three environmental variables were used in modeling predicted catches for the Tanana River. Once the best model was selected based on AIC for each species/taxa at each location, a smoother trend line ± 95% CI was plotted to visually describe the effects of each environmental variable on catches. Each environmental variable included in the best fit model was determined to have an association with catches if the smoothing parameter from each variable was significantly different from zero, assessed at the $\alpha = 0.05$ level.

To examine possible associations between catches and river discharge, a smoothed trend line ± 95% CI for each species/taxa (equation 2) from each location was overlaid on a plot of mean daily river discharge and visually assessed for co-occurrence of peaks/trends in catches and discharge. This approach was used based on the *a priori* assumption that increasing or decreasing trends in discharge, not the absolute value of discharge, would have the strongest association with catches.

Results

Catch composition

In the Yukon River, 499 fyke net sets were made from 28 May 2010 to 22 September 2010 ($4.9 \cdot day^{-1} \pm 1.8$ [mean ± 1 SD], range 1–10) (Figure 3). The duration of each fyke net set (61 ± 41 minutes, range 20–210 min) varied due to debris load. At least ten species were captured, with longnose suckers having the highest CPUE followed by Arctic grayling, whitefishes, chum salmon, Chinook salmon, lake chub, *Lethenteron* spp., burbot, inconnu, slimy sculpin, and Arctic lamprey (Table 1).

In the Tanana River, 384 fyke net sets were made on the river margins from 12 May 2011 to 28 August 2011 ($4.2 \cdot day^{-1} \pm 1.7$, range 1–7) (Figure 3). The duration of each fyke net set (30 ± 3 minutes, range 24–60 min) was relatively consistent among sets. In the river margins, at least 11 species were captured, with whitefishes having the largest CPUE followed by longnose suckers, chum salmon, lake chub, *Lethenteron* spp., burbot, Arctic grayling, Chinook/coho salmon, slimy sculpin, Arctic lamprey, Alaskan brook lamprey, and northern pike (Table 1).

Seventy-three incline plane trap sets were made in the mid-channel of the Tanana River from 20 May 2011 to 18 August 2011 ($2 \cdot day^{-1} \pm 0.7$, range 1–3) (Figure 3). The duration of each incline plane trap set (63 ± 23 minutes, range 20–160 min) varied depending on duration of concurrently set fyke nets. In late-June, the incline plane trap required significant modification and repair and, as a result, was not operational again until late-July. In the surface waters of the mid-channel, at least six species were captured, with Chinook/coho salmon and chum salmon having the largest CPUE followed by whitefishes, Arctic lamprey, *Lethenteron* spp., and burbot (Table 1).

Depending on size and time of capture, ages of some fish could be inferred. For example, a majority of Yukon River Chinook salmon, whitefishes, and Arctic grayling and Tanana River whitefishes were age 0 and their fork length increased as the sampling season progressed. In contrast, a majority of Tanana River Chinook/coho salmon were age 1+ and their fork length did not increase as the sampling season progressed (Figure 4).

Temporal patterns

Several species/taxa of fishes displayed a distinct seasonal peak in catches in one or more sampling locations in both the Yukon and Tanana rivers (Figure 5). The date-smoothing parameter (equation 2) for catches of chum salmon (left margin: F-statistic = 3.63, equivalent degrees of freedom (edf) = 11.39, $P = 0.0011$) and whitefishes (left margin: F-statistic = 7.50, edf = 9.70, $P < 0.0001$; right margin: F-statistic = 6.97, edf = 11.36, $P < 0.0001$) in the Yukon River indicates both species/taxa exhibited peaks in catches in early July and Arctic grayling (left margin: F-statistic = 10.11, edf = 11.83, $P < 0.0001$; right margin: F-statistic = 20.97, edf = 10.78, $P < 0.0001$) peaked in catches in mid-August (Table 2; Figure 5). The date-smoothing parameter (equation 2) for catches in the Tanana River of longnose suckers (right margin: F-statistic = 4.84, edf = 11.84, $P<0.0001$) indicates they exhibited a small peak in catches in late-May and whitefishes catch (left margin: F-statistic = 7.03, edf = 7.82, $P < 0.0001$; right margin: F-statistic = 22.37, edf = 12.67, $P < 0.0001$) peaked in late-June (Table 3; Figure 5).

Several species of fish also displayed increasing or decreasing trends in catches (Figure 5). For example, the date-smoothing parameter (equation 2) for catches in the Yukon River of chum salmon (middle island: F-statistic = 7.08, edf = 8.45, $P < 0.0001$) indicates a decreasing trend from late-May through July and longnose suckers (left margin: F-statistic = 7.62, edf = 12.65, $P < 0.0001$; middle island: F-statistic = 8.69, edf = 5.08, $P < 0.0001$; right margin: F-statistic = 9.19, edf = 11.43, $P < 0.0001$) exhibited an increasing trend in late-June, sustained high catches through August, then a decreasing trend. The date-smoothing parameter (equation 2) for catches in the Tanana River of chum salmon (left margin: F-statistic = 14.95, edf = 7.10, $P < 0.0001$), Chinook/coho salmon (mid-channel: F-statistic = 8.89, edf = 5.21, $P < 0.0001$), and longnose suckers (left margin: F-statistic = 30.57, edf = 1.00, $P = 0.0001$) indicates a decreasing trend through the sampling season and lake chub (right margin: F-statistic = 3.27, edf = 11.05, $P = 0.0002$) initially decreased, then remained low throughout the remainder of the sampling season (Table 3: Figure 5).

In contrast to the previously described species/taxa which exhibited either peaks or trends in downstream migration abundance, chum salmon in the mid-channel and right margin of the Tanana River exhibited both. The date-smoothing parameter (equation 2) for catches of chum salmon in the mid-channel (F-statistic = 5.22, edf = 6.47, $P = 0.0002$) indicates a decreasing trend late-May through early June, then a peak in mid-June, and on the right margin (F-statistic = 16.69, edf = 10.08, $P < 0.0001$), a decreasing trend in mid-May immediately followed by a peak in mid/late May (Table 3; Figure 5).

Akaike Information Criterion comparisons of equations (2) and (3) indicate that time-of-day improved model fit for longnose suckers on both the right margin of the Yukon River (ΔAIC = 6.2, F-statistic = 6.92, edf = 15.47, $P < 0.0001$) and left margin of the Tanana River (ΔAIC = 21.6, F-statistic = 3.85, edf = 19.96, $P < 0.0001$) and Arctic grayling on the right margin of the Yukon River (ΔAIC = 18.1, F-statistic = 17.62, edf = 17.36, $P < 0.0001$) (Table 2 and 3). Visual assessment of contour plots suggests that on the right margin of the Yukon River, catches of longnose suckers were highest in the evening hours in early July and early morning hours in mid-August while catches of Arctic grayling increased in the evening hours in June and September (Figure 6). In the Tanana River, catches of longnose suckers on the left margin of the river were highest in the late evening in late-May and early to late morning in mid/late June (Figure 6).

In contrast to the species/taxa that exhibited seasonal and/or diel temporal patterns, the remaining species/taxa captured in the Yukon River margins (Chinook salmon, inconnu, slimy sculpin, *Lethenteron* spp., Arctic lamprey, lake chub, and burbot), Tanana River margins (Chinook/coho salmon, Arctic grayling, slimy sculpin, *Lethenteron* spp., Arctic lamprey, Alaskan brook lamprey, burbot, and northern pike) and Tanana River mid-channel (whitefishes, Arctic grayling, Arctic lamprey, *Lethenteron* spp., and burbot) did not display temporal patterns in catches as their frequency of occurrence was too small to identify seasonal or diel trends or peaks in migration.

Spatial patterns

In the Tanana River, catches of Chinook salmon and coho salmon primarily occurred in the mid-channel while chum salmon occurred in both the mid-channel and river margins. Of the species/taxa captured in the Tanana River margins, catches of whitefishes and longnose suckers were primarily larger on the right margin and catches did not differ between margins for lake chub or chum salmon.

Catches of whitefishes, longnose suckers, and Arctic grayling were much larger on the left and right margins than the middle island in the Yukon River. Besides a peak in catches of chum salmon that occurred on the left margin of the Yukon River in early July, catches of chum salmon did not differ between the margins and middle island.

Environmental correlates

In both the Yukon and Tanana rivers, discharge exhibited an increasing trend until early/mid-July, then a decreasing trend through the end of the sampling season, with regular fluctuations of 400 to 1,400 $m^3 \cdot s^{-1}$ in the Yukon River, sometimes occurring in less than 12 hours (Figure 7). Mean daily water temperature showed an increasing trend through May in the Tanana River, after which both rivers generally ranged from 13 to 17°C, until the temperature steadily decreased starting in late-July in the Tanana River and mid-August in the Yukon River (Figure 7). Turbidity in the Tanana River was relatively high when measurements began in mid-May, immediately decreased for one week, then increased until late-May and remained high through the remainder of the sampling season. In the Yukon River, turbidity was relatively low when measurements began in June, increased through mid-August, then decreased at the end of the sampling season (Figure 7). The daily mean of the Debris Index exhibited multiple distinct peaks throughout the summer in both rivers (Figure 7). Highest debris counts occurred in May in the Tanana River and in July and August in the Yukon River. There appears to be a strong association between discharge and the Debris Index in the Yukon River as each peak of the Debris Index corresponds to a peak in discharge.

Model selection based on AIC indicates that environmental variables measured in this study were associated with catches in both the Yukon (Table 2) and Tanana rivers (Table 3). The Debris Index was associated with catches of whitefishes in both the Yukon (left margin: F-statistic = 6.60, edf = 1.82, $P = 0.0027$; right margin: F-statistic = 5.94, edf = 1.71, $P = 0.0038$) and Tanana River (right margin: F-statistic = 13.23, edf = 1.00, $P = 0.0004$), longnose suckers in both the Yukon (Figure 8) (left margin: F-statistic = 24.49, edf = 1.82, $P < 0.0001$; middle island: F-statistic = 8.98, edf = 1.00, $P = 0.0030$; right margin: F-statistic: 11.10, edf = 1.46, $P < 0.0001$) and Tanana River (left margin: F-statistic = 6.00, edf = 1.95, $P = 0.0031$), and Arctic grayling in the Yukon River (left margin: F-statistic = 6.74, edf = 1.89, $P = 0.0022$). In each case, catches increased with increasing values of the Debris Index, except catches of whitefishes in the Tanana River, which decreased. Decreased catches with increased water temperatures of the Tanana River were observed for chum salmon (right margin: F-statistic = 6.03, edf = 1.74, $P = 0.0042$), whitefishes (right margin: F-statistic = 8.00, edf = 1.92, $P = 0.0005$), longnose suckers (right margin: F-statistic = 3.52, edf = 2.00, $P = 0.0315$), and lake chub (left margin: F-statistic = 5.62, edf = 1.00, $P = 0.0188$; right margin: F-statistic = 8.07, edf = 1.76, $P = 0.0006$) In contrast, increased catches with increased water temperatures in the

Yukon River were observed for longnose suckers (middle island: F-statistic = 11.91, edf = 1.00, P = 0.0006) and Arctic grayling (middle island: F-statistic = 5.10, edf = 2.00, P = 0.0068). Decreased catches with decreased turbidity in the Tanana River were observed for whitefishes (right margin: F-statistic = 5.21, edf = 1.93, P = 0.0064) and longnose suckers (left margin: F-statistic = 3.95, edf = 1.00, P = 0.0486; right margin: F-statistic = 3.35, edf = 2.00, P = 0.0371). Qualitative visual assessment of seasonal patterns in catches indicates that chum salmon (Yukon River left margin and Tanana River right margin and mid-channel), whitefishes (Yukon River left margin (Figure 9) and Tanana River left and right margins), Chinook/coho salmon (Tanana River mid-channel), and longnose suckers (Tanana River right margin) were associated with increasing river discharge.

Discussion

Catch composition

Size, time of capture, and published accounts of life histories may be used to infer age and migratory destinations of these juvenile fishes. All of the chum salmon captured in both rivers were age-0 smolts migrating to the Bering Sea, as this species does not rear in freshwater, but rather migrates to the ocean soon after emergence from spawning gravel (Scott and Crossman, 1973). Based on time of capture and fork length, all but one Chinook salmon captured in the Yukon River were age-0 fry moving down river to overwinter in non-natal streams (Daum and Flannery, 2011). In contrast, in the Tanana River, based on time of capture and fork length, a majority of Chinook and coho salmon were age-1 and age-2 smolts, respectively (Pearse, 1974; Evenson, 2002) migrating to the

Bering Sea. The limited catches of age-0 Chinook/coho salmon fry in the Tanana River suggest that these species either do not move down river to overwinter in non-natal streams, as has been documented in the Yukon River (Daum and Flannery, 2011), or were not captured in the sampling gear.

While some Arctic grayling and whitefishes were age 1+, the vast majority were age 0. Age-0 whitefishes began appearing in catches in early June and unfortunately, without morphological or genetic confirmation, it is nearly impossible to definitively identify species (Shestakov, 1991; Bradford *et al.*, 2008). Since the focus of this study was on the general species community, grouping whitefishes into a single category did not negatively affect the study objectives. However, when possible, round whitefish were informally distinguished from whitefishes belonging to the genus *Coregonus*, based on presence of parr marks, and this species made up a minimum of 53% and 70% of catches of whitefishes in the Yukon and Tanana rivers. In contrast, other studies in the Yukon (Bradford *et al.*, 2008) and Tanana (Mecum, 1984; Ott *et al.*, 1998) rivers had relatively few numbers of round whitefish compared to other whitefishes. This contradiction is likely based on the fact the other studies in the Tanana River (Mecum, 1984; Ott *et al.*, 1998) focused on residence and feeding in mainstem and backwater areas by capturing whitefishes with baited minnow traps, thereby not capturing the significant, but brief downstream migration of age-0 whitefishes in late-June, documented in this study, while the Yukon River study (Bradford *et al.*, 2008) captured many "unidentified Coregoninae," many of which may have been round whitefish.

Age-0 Arctic grayling began appearing in catches in the Yukon River in early July, which coincided with a high discharge event suggesting they were flushed out of their natal streams shortly after hatching (Junk *et al.*, 1989). However, these catches were small and the majority of age-0 Arctic grayling were captured in early to mid-August, suggesting the onset of the early fall downstream migration from natal rearing and feeding areas to overwintering areas (Tack, 1980; Walker, 1983). Similar patterns have been observed upstream in the Yukon River (Bradford *et al.*, 2008) and elsewhere in Alaska (Craig and Poulin, 1975). The minimal catches of age-0 Arctic grayling in the Tanana River indicate that it does not serve as primary summer rearing habitat (Ott *et al.*, 1998) and either the fall downstream migration of fry occurred after sampling ceased, or this section of the Tanana River may not serve as a migration route for fry moving to overwintering habitat.

Although age 0 and age 1+ of other species were captured, distinguishing ages of these other species was less obvious. Based on known length-age relationships for longnose suckers in Alaska, it is probable that 97% and 94% of the longnose suckers captured in in the Yukon and Tanana rivers were age 0 and age 1 (Pierce, 1977; Mecum, 1984). Reasons for occurring in the Yukon and Tanana River mainstems are likely different depending on age and time of year, but it is likely they use mainstems as a migration corridor to access backwater areas, which are productive areas for juvenile longnose suckers (Mecum, 1984; Ott *et al.*, 1998).

Catches of lake chub were small in this study in the Yukon River at Eagle, AK, and another study near Dawson, YT, but it is believed they occur closer to the headwaters where turbidity decreases (Bradford *et al.*, 2008). In contrast, lake chub in the Tanana River in this study were more abundant, corroborating previous research that found that they are the most commonly captured species in the Tanana River drainage, particularly in backwater habitats (Mecum, 1984; Ott *et al.*, 1998).

The vast majority of lamprey captured in both the Yukon and Tanana rivers were ammocoetes with the exception of a few adult Arctic lamprey and two gravid Alaskan brook lamprey. Arctic lamprey ammocoetes have been described as having a nocturnal downstream migration, tightly associated with high discharge events in Russia (Kirillova *et al.*, 2011); however, catch rates were too small in this study to document any such patterns. Additionally, the ammocoetes captured in this study may not have been migrating, but rather actively or passively moving between feeding habitats. The adult Arctic lamprey were captured in mid-June in both the river margins and mid-channel while the Alaskan brook lamprey were captured in early June in the river margins. It is likely all adults captured were pre-spawners (T. Sutton, UAF, personal communication).

Inconnu in the Yukon River, northern pike in the Tanana River, and burbot and slimy sculpin in both river systems were captured in relatively few numbers, likely because of relatively sedentary behavior and/or preference for other habitats. Young of the year inconnu have been documented as moving downstream in the Yukon River mainstem late-July through August, likely from spawning locations to feeding areas (Alt, 1987) which coincides with time of capture in this study. Northern pike are typically found in areas with aquatic vegetation and less turbid waters, as found in Minto Flats in the Tanana River drainage, which likely explains the low capture rates in this study.

Burbot are known to occur in a variety of habitats in interior Alaska, including large glacial rivers, but are relatively sedentary, except for movements from November to March, likely associated with winter spawning (Breeser *et al.*, 1988). This likely explains their low capture rates in this study, though they may also occur in habitats not sampled, such as the bottom of the mid-channel. Additionally, slimy sculpin are typically more abundant in clear headwater streams (Craig and Wells, 1976). It is likely catches of northern pike, burbot, and slimy sculpin in this study do not reflect migrations, but rather active or passive movements within the mainstems.

Temporal patterns and environmental correlates

The association between river discharge and peaks of catches of chum salmon and whitefishes in both rivers and longnose suckers and Chinook/coho salmon in the Tanana River suggests that these fish are either physically displaced from tributaries and backwater areas during high water (Wolter and Sukhodolov, 2008) or use increasing discharge as a cue to initiate downstream migration (Lucas and Baras, 2001; Achord *et al.*, 2007). For each of these species/taxa, catches appear to be associated with only one high discharge event, suggesting that a majority of the fish migrated downstream in one pulse. As a result, fewer juveniles remained in the tributaries later in the year, thus the association between catches and high discharge events was reduced (Whalen *et al.*, 1999). Multiple studies have documented a similar pattern for chum salmon smolts in the Yukon River (Gissberg and Benning, 1965), Tanana River drainage (Francisco, 1977; Peterson, 1997), and elsewhere in Alaska (Burril *et al.*, 2009). Additionally, similar patterns have been documented for Chinook salmon smolts in the Chena River (Peterson, 1997), and whitefishes in other locations (Shestakov, 1991).

While longnose suckers did not exhibit any significant peaks in catch in the Yukon River, it was likely that the smoother trendline and wide 95% CI produced by the GAM masked considerable peaks that occurred. When the raw daily mean CPUE data of longnose suckers in the Yukon River were examined and compared to river discharge, it was evident that catches of longnose suckers were strongly associated with subsequent peaks in discharge throughout a majority of the open-water season (Figure 10). This suggests that heavy rainfall events responsible for increased discharge, called freshets, flush juvenile longnose suckers out of small tributaries and these juvenile fish cannot swim against the increased water velocity of the mainstem of the river to return to their natal tributary (Junk *et al*., 1989). These results support the association of longnose suckers with woody debris in the river, explained by the GAM, as high discharge events also resulted in large amounts of woody debris in the river (Figure 10).

In addition to increasing discharge, increasing water temperature may also act as a cue to initiate downstream migration. For example, as water temperatures increased, catches of chum salmon and lake chub in the Tanana River decreased. It is likely chum salmon initiated downstream migration with the initial spring increase in water temperature, which coincided with increasing discharge, suggesting that chum salmon smolts may be both physically displaced by high discharge and use increasing water temperature as a cue for downstream migration. The period of high catches of lake chub in the Tanana River coincided with low water temperatures in mid-May, which may be a response to changing water temperatures in tributaries and backwater habitats. Ripe and spawning lake chub have been reported in a small Tanana River tributary in mid-July (Ott *et al*., 1998), so the high catches of lake chub in mid-May may have been a result of movement from overwintering habitat to summer rearing/spawning habitat, possibly cued by increasing water temperature.

It is likely that the remaining associations between seasonal temporal patterns and environmental variables were spurious relationships, resulting in type-I error. Many of the significant environmental variables had a very marginal effect on catches for a species/taxa, as the smoother trendline contained very wide 95% CI's. Additionally, since many of these associations only occurred with catches at one sampling location and not on the other river margin, they were likely not biologically significant.

Although there is evidence for a diel pattern in downstream migration of longnose suckers in both rivers and Arctic grayling in the Yukon River, this was likely another spurious relationship for several reasons. First, the diel effects were weak as the contour lines on the contour plot were primarily vertical. Second, there is minimal darkness in the summer and these patterns only occurred in one sampling location. Lastly, sampling effort was minimal in the late-night/early morning hours in the Yukon River resulting in a small sample size.

While some of the species/taxa captured in this study are known to exhibit diel patterns in other rivers, the lack of diurnal patterns of these fishes, particularly salmon smolts, is not surprising. Generally, downstream migrating salmon smolts exhibit nocturnal behavior in low turbidity systems and less distinct diel patterns in turbid systems (Gregory and Levings, 1998). One hypothesis for this pattern is that smolts migrate during times of decreased visibility to minimize the chance of predation by piscivorous fishes (Gregory and Levings, 1998). As such, in low turbidity environments where visibility is relatively high, smolts generally migrate downstream at night to reduce the chance of visual detection by predators (Gregory and Levings, 1998). In contrast, in highly turbid environments, such as the Yukon and Tanana rivers, visibility is low throughout the ice-free season, regardless of solar light level, thus downstream migration occurs at all times of the day (Gregory and Levings, 1998).

Continuous downstream migration as a result of low water visibility may be reinforced by the relatively long distance (> 800 km) to their oceanic destination, which necessitates twenty-four hour travel by the smolts so their arrival time coincides with the productive, but short summer (Chittenden *et al.*, 2010). In contrast, in systems with low water visibility, yet much shorter migration distances (< 100 km) such as the Taku River, salmon smolts exhibit nocturnal migration timing (Meehan and Siniff, 1962), likely to avoid reaching the ocean too early.

<u>Spatial patterns</u>

Most species/taxa captured in this study primarily utilized either the river margins or the mid-channel, but not both. Chinook and coho salmon were the only species to primarily utilize the mid-channel in the Tanana River. Similar patterns have been documented for Chinook salmon in the Columbia River (Dauble *et al.*, 1989). In the Yukon River, it was initially hypothesized that the middle island would serve as a proxy for mid-channel habitat however; only one Chinook salmon smolt was captured there.

The lack of catches of Chinook salmon smolts in the Yukon River suggest either outmigration was near completion by the time sampling began in late-May (Bradford *et al.*, 2008), or they were utilizing the swifter waters of the mid-channel, making them not vulnerable to sampling gear on the river margins or middle island.

The remaining species/taxa were primarily captured in the river margins of both rivers. Tributary and backwater habitat use has been documented for many of these species/taxa (Mecum, 1984; Ott *et al.*, 1998; Durst, 2001; Daum and Flannery, 2011) and it is likely the margins of the Yukon and Tanana River mainstems serve as important migratory corridors between these habitats.

While most species/taxa's abundance was similar in both the left and right margins, such as lake chub in the Tanana River and longnose suckers, Arctic grayling, and whitefishes in the Yukon River, other species/taxa did not conform to this pattern, such as whitefishes and longnose suckers in the Tanana River, whose catches were consistently higher on the right margin of the river. One likely explanation is that lateral distribution of these two species/taxa within the river is influenced by hydrodynamic forces, as most larval and juvenile fishes have critical swimming speeds less than $0.4\ m \cdot s^{-1}$, well below the average velocity found in large rivers, such as the Tanana River (Jones *et al.*, 1974; Wolter and Sukhodolov, 2008). If hydrodynamic forces do influence juvenile and larval fishes in the Tanana River, such as longnose suckers and whitefishes, they will likely show smaller relative abundances on the margins in inside bends, where the fast current likely carries them towards the opposite bank. Because sampling locations on both river margins in the Yukon River were located in inside bends, catches did not differ between margins as hydrodynamic forces were likely similar between sampling locations for each species/taxa.

In contrast to the previously described species/taxa, chum salmon smolts were distributed throughout the river channel in both rivers. Other studies have documented a similar pattern with chum salmon in the Yukon River (Gissberg and Benning, 1965) and Fraser River in British Columbia (Todd, 1966). Because chum salmon smolts feed during their long migration to the ocean (Durst, 2001), it is possible they utilize the margins for feeding and the mid-channel for traveling.

Implications

This study has shown that, for a hydrokinetic device mounted in the surface of the mid-channel of the Tanana River, most potential for interactions with fishes occur with Chinook salmon, coho salmon and chum salmon smolts as they migrate downstream to the ocean May through July, particularly during periods of increasing discharge. Unfortunately, since Chinook salmon and coho salmon were not distinguished, it is unknown if Chinook salmon or coho salmon would have higher potential for interactions. In the upper Yukon River, the potential for interactions would be limited to Chinook salmon and chum salmon smolts as coho salmon have not been documented near the international border. Should hydrokinetic technology be implemented in these rivers, future research should be conducted to determine if interactions between hydrokinetic devices and fishes do occur, and if so, what physical impacts they may have on fishes. Additionally, this study was limited to downstream migrating fishes so the potential for interactions of fish moving upstream remain unknown.

Literature Cited:

Achord SR, Zabel W, Sanford BP. 2007. Migration timing, growth, and estimated parr-to-smolt survival rates of wild Snake River spring-summer Chinook salmon from the Salmon River basin, Idaho, to the lower Snake River. *Transactions of the American Fisheries Society* **136**: 142-154. DOI: 10.1577/T05-308.1.

Akaike H. 1973. Information theory and an extension of the maximum likelihood principle. In B. N. Petrov and F. Csaki (Eds.), Proceedings of the Second International Symposium on Information Theory, pp. 267–281. Budapest: Akademiai Kiado.

Alt KT. 1987. Review of sheefish (Stenodus leucichthys) studies in Alaska. Fishery Manuscript No. 3. Alaska Department of Fish and Game, Division of Sport Fish.

Beacham TD, Murray CB, Withler RE. 1989. Age, morphology, and biochemical genetic variation of Yukon River Chinook salmon. *Transactions of the American Fisheries Society* **118**: 46–63.

Borba BM. 2007. Test fish wheel project using video monitoring techniques, Tanana River, 2003. Fishery Data Series No. 07-55. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries.

Brabets TP, Wang B, Meade RH. 2000. Environmental and hydrologic overview of the Yukon River basin, Alaska and Canada. U.S. Geological Survey, Water-Resources Investigations Report 99-4204.

Bradford MJ, Duncan J, Jang JW. 2008. Downstream migration of juvenile salmon and other fishes in the upper Yukon River. *Arctic* **61**: 255–264.

Breeser SW, Stearns FD, Smith MW, West RL, Reynolds JB. 1988. Observations of movements and habitat preferences of burbot in an Alaskan glacial river system. *Transactions of the American Fisheries Society* **117**: 506–509.

Brown RJ, Brown C, Braem NM, Carter WK, Legere N, Slayton L. 2011. Whitefish and whitefish fisheries in the Yukon and Kuskokwim River drainages in Alaska: a status review with recommendations for future research directed towards sustainable management. U. S. Fish and Wildlife Service, Alaska Department of Fish and Game. Fisheries Resources Monitoring Program Draft Report.

Brown RJ, Bickford N, Severin K. 2007. Otolith trace element chemistry as an indicator of anadromy in the Yukon River drainage coregonine fishes. *Transactions of the American Fisheries Society* **136**: 678–690. DOI: 10.1577/T06-040.1.

Brown RJ, Lunderstadt C, Schulz B. 2002. Movement patterns of radio-tagged adult humpback whitefish in the Upper Tanana River drainage. Alaska Fish Data Series No 2002-1, U.S. Department of the Interior, Fish and Wildlife Service, Region 7, Fishery Resources.

Buklis LS, Barton LH. 1984. Yukon River fall chum salmon biology and stock status. Alaska Department of Fish and Game Informational Leaflet No. 239.

Burnham, KP, Anderson DR, Huyvaert KP. 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observations and comparisons. *Behavioral Ecology and Sociobiology* **65**: 23–35. DOI: 10.1007/s00265-010-1029-6.

Burril SE, Zimmerman CE, Finn JE, Gillikin D. 2009. Abundance, timing of migration, and egg-to-smolt survival of juvenile chum salmon, Kwethluk River, Alaska. U.S. Department of the Interior. Project 619.

Cada GF. 1990. A review of studies relating to the effects of propeller-type turbine passage on fish early life stages. *North American Journal of Fisheries Management* **10**:418–426.

Cada GF. 2001. The development of advanced hydroelectric turbines to improve fish passage survival. *Fisheries* **26**:14–23.

Chittenden CM, Jensen JLA, Ewart D, Anderson S, Balfry S, Downey E, Eaves A, Saksida S, Smith B, Vincent S, Welch D, McKinley RS. 2010. Recent salmon declines: A result of lost feeding opportunities due to bad timing? PLoS ONE **5**: e12423. DOI: 10.1371/journal.pone.0012423.

Coutant CC, Whitney RR. 2000. Fish behavior in relation to passage through hydropower turbines: A review. *Transactions of the American Fisheries Society* **129**: 351–380.

Craig PC, Poulin VA. 1975. Movements and growth of Arctic grayling (Thymallus arcticus) and juvenile Arctic char (Salvelinus alpinus) in a small arctic stream, Alaska. *Journal of the Fisheries Research Board of Canada* **32**: 689–697.

Craig PC, Wells J. 1976. Life history notes for a population of slimy sculpin (Cottus cognatus) in an Alaskan Arctic stream. *Journal of the Fisheries Research Board of Canada* **33**: 1639–1642.

Dahlberg ML, Phinney DE. 1967. The use of adipose fin pigmentation for distinguishing between juvenile Chinook and coho salmon in Alaska. *Journal of the Fisheries Research Board of Canada* **24**: 209–210.

Dauble DD, Page TL, Hanf RW. 1989. Spatial distribution of juvenile salmonids in the Hanford Reach, Columbia River. *Fishery Bulletin* **87**: 775–790.

Daum DW, Flannery BG. 2011. Canadian-origin Chinook salmon rearing in non-natal U.S. tributary streams of the Yukon River, Alaska. *Transactions of the American Fisheries Society* **140**: 207–220. DOI: 10.1080/00028487.2011.545004.

Durst JD. 2001. Fish habitats and use in the Tanana River floodplain near Big Delta, Alaska, 1999-2000. Technical Report No. 01-05. Alaska Department of Fish and Game, Habitat and Restoration Division.

EPRI (Electric Power Research Institute). 2011. Evaluation of Fish Injury and Mortality Associated with Hydrokinetic Turbines. Palo Alto, California. Report # 1024569.

Evenson MJ. 2002. Optimal production of Chinook salmon from the Chena and Salcha rivers. Fishery Manuscript Series No. 02-01. Alaska Department of Fish and Game, Division of Sport Fish.

Francisco K. 1977. Second interim report of the commercial fish technical evaluation study. Special Report No. 9, Joint State/Federal Fish and Wildlife Advisory Team, Alaska Department of Fish and Game.

Gissberg JG, Benning DS. 1965. Yukon foundation studies summary report, 1965. U. S. Department of Interior, Fish and Wildlife Service.

Gregory RS, Levings CD. 1998. Turbidity reduces predation on migrating juvenile Pacific salmon. *Transactions of the American Fisheries Society* **127**: 275–285.

Hastie TJ, Tibshirani RJ. 1990. *Generalized Additive Models*. London: Chapman & Hall.

Hemming CR, Morris WA. 1999. Fish habitat investigations in the Tanana River watershed, 1997. Technical Report No. 99-01. Alaska Department of Fish and Game, Habitat and Restoration Division.

Jones DR, Kiceniuk JW, Bamford OS. 1974. Evaluation of the swimming performance of several fish species from the Mackenzie River. *Journal of the Fisheries Research Board of Canada* **31**: 1641–1647.

Junk WJ, Bailey PB, Sparks RE. 1989. The flood pulse concept in large river-floodplain systems. Proceedings of the International Large River Symposium. *Canadian Special Publications of Fisheries and Aquatic Sciences* **106**: 110–117.

Kirillova EA, Kirillov PI, Kucheryavyy AV, Pavolv DS. 2011. Downstream migration in ammocoetes of the Arctic Lamprey (Lethenteron camtschaticum) in some Kamchatka Rivers. *Journal of Ichthyology* **51**: 1117–1125. DOI: 10.1134/S0032945211110051.

Kucheryavyi AV, Savvaitova KA, Pavlov DS, Gruzdeva MA, Kuzishchin KV, Stanford JA. 2007. Variations of life history strategy of the Arctic lamprey (Lethenteron camtschaticum) from the Utkholok River (Western Kamchatka). *Journal of Ichthyology* **47**: 37–52. DOI: 10.1134/S0032945207010055.

Lambert TM. 1998. Heterogeneity and bias in abundance estimates of outmigrating Chinook salmon in the Chena River, Alaska. *M.S. Thesis*, University of Alaska Fairbanks.

Lucas MC, Baras E. 2001. *Migration of Freshwater Fishes*. Blackwell Science, Oxford, UK.

Mains EM, Smith JM. 1964. The distribution size, time and current references of seaward migrant Chinook salmon in the Columbia and Snake rivers. Washington State Department of Fish. *Fisheries Research Papers* **2**: 5–43.

McKeown BA. 1984. *Fish Migration*. Timber Press, Beaverton, Oregon.

McPhail JD, Paragamian VL. 2000. Burbot biology and life history. *Fisheries Management section of the American Fisheries Society* **128**: 10–23.

Mecklenburg CW, Mecklenburg TA, Thorsteinson LK. 2002. *Fishes of Alaska*. American Fisheries Society. Bethesda, Maryland.

Mecum RD. 1984. Habitat utilization by fishes in the Tanana River near Fairbanks, AK. *M.S. Thesis*, University of Alaska Fairbanks.

Meehan WR, Siniff DB. 1962. A study of the downstream migrations of anadromous fishes in the Taku River, Alaska. *Transactions of the American Fisheries Society* **91**: 399–407.

Melnychuk MC, Welch DW, Walters CJ. 2010. Spatio-temporal migration patterns of Pacific salmon smolts in rivers and coastal marine waters. *PLoS ONE* **5**: e12916. DOI: 10.1371/journal.pone.0012916.

Muhlfield CC, Bennett DH, Steinhorst RK, Marotz B, Boyer M. 2008. Using bioenergetics modeling to estimate consumption of native juvenile salmonids by nonnative northern pike in the upper Flathead River system, Montana. *North American Journal of Fisheries Management* **28**: 636–648. DOI: 10/1577M07-004.1.

Northcote, TG. 1997. Potamodromy in Salmonidae–living and moving in the fast lane. *North American Journal of Fisheries Management* **17**: 1029–1045.

Ott AG, Winters JF, Townsend AH. 1998. Juvenile fish use of selected habitats in the Tanana River near Fairbanks (preliminary report). Technical Report No. 97-1. Alaska Department of Fish and Game, Habitat and Restoration Division.

Parker JF. 1991. Status of coho salmon in the Delta Clearwater River of interior Alaska. Fishery Manuscript No. 91-4. Alaska Department of Fish and Game, Division of Sport Fish.

Pearse GA. 1974. A study of a typical spring fed stream of interior Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, 1973–1975, Project F-9-6(15)G-III-G.

Peterson BD. 1997. Estimation of abundance and mortality of emigrating chum salmon and Chinook salmon in the Chena River, Alaska. *M.S. Thesis*, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks.

Pierce GS. 1977. Spawning migration and population structure of longnose sucker (Catostomus catostomus) in Alaska. *M.S. Thesis*, University of Idaho

Raymond JA. 1986. Growth of wild and hatchery juvenile coho salmon in an interior Alaskan stream. Report No. 60. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement and Development.

Schweizer PE, Cada GF, Bevelhimer MS. 2012. Laboratory experiments on the effects of blade strike from hydrokinetic energy technologies on larval and juvenile freshwater fishes. Oak Ridge National Laboratory. Report # ORNL/TM-2012/108.

Scott WB, Crossman EJ. 1973. *Freshwater Fishes of Canada*. Fisheries Research Board of Canada. Bulletin 184, Ottawa.

Seitz AC, Moerlein K, Evans MD, Rosenberger AE. 2011. Ecology of fishes in a high-latitude, turbid river with implications for the impacts of hydrokinetic devices. *Reviews in Fish Biology and Fisheries* **21**: 481–496. DOI: 10.1007/s11160-011-9200-3.

Shestakov AV. 1991. Preliminary data on the dynamics of the downstream migration of coregonid larvae in the Anadyr River. *Journal of Ichthyology* **31**: 65–74.

Spence BC, Hall JD. 2010. Spatiotemporal patterns in migration timing of coho salmon (Oncorhynchus kisutch) smolts in North America. *Canadian Journal of Fisheries and Aquatic Sciences* **67**: 1316–1334. DOI: 10.1139/F10-060.

Sutton TM, Bowen SH. 1994. Significance of organic detritus in the diet of larval lampreys in the Great Lakes basin. *Canadian Journal of Fisheries and Aquatic Sciences* **51**: 2380–2387.

Tack S. 1980. Migrations and distributions of Arctic grayling, (Thymallus arcticus) (Pallas), in Interior and Arctic Alaska. Alaska Department of Fish and Game, Sport Fish Division. Federal Aid in Fish Restoration, Annual Performance Report, 1980-1981, Project F-9-12(21)R-I.

Todd GL. 1994. A lightweight, inclined-plane trap for sampling salmon smolts in rivers. *Alaska Fishery Research Bulletin* **1**: 168–175.

Todd IS. 1966. A technique for the enumeration of chum salmon fry in the Fraser River, British Columbia. *The Canadian Fish Culturist* **38**: 3–35.

Tyler RW. 1979. Method of sampling seaward migrations of juvenile salmon. *The Progressive Fish-Culturist* **41**: 78–81.

Venables WN, Dichmont CM. 2004. GLMs, GAMs, and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research* **70**: 319–337. DOI: 10.1016/j.fishres.2004.08.011.

Vladykov VD, Kott E. 1978. A new nonparasitic species of the holarctic lamprey genus Lethenteron Creaser and Hubbs, 1922, (Petromyzonidae) from northwestern North America with notes on other species of the same genus. Biological Papers of the University of Alaska, Number 19.

Walker RJ. 1983. Growth of young-of-the-year salmonids in the Chena River, Alaska. *M. S. Thesis*, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks.

West RL, Smith MW, Barber WE, Reynolds JB, Hop H. 1992. Autumn migration and overwintering of Arctic grayling in coastal streams of the Arctic National Wildlife Refuge. *Transactions of the American Fisheries Society* **121**: 709–715.

Whalen KG, Parrish DL, McCormick SD. 1999. Migration timing of Atlantic salmon smolts relative to environmental and physiological factors. *Transactions of the American Fisheries Society* **128**: 289–301.

Whitney RR, Calvin LD, Erho MW, Coutant CC. 1997. Downstream passage for salmon at hydroelectric projects in the Columbia River basin: Development, installation, and evaluation. Report Number 97-15 for the Northwest Power Planning Council.

Wolter C, Sukhodolov A. 2008. Random displacement versus habitat choice of fish larvae in rivers. *River Research and Applications* **24**: 661–672. DOI: 10.1002/rra.1146.

Table 1. CPUE (# fish·1,000 m^{-3}) and mean fork/total length (mm) for each species/taxa captured in the Yukon River margins at Eagle, AK and Tanana River margins and mid-channel at Nenana, AK.

	Yukon River Margins		Tanana River Margins		Tanana River Mid-channel	
Species	CPUE ± 1 SE	Mean length (mm) ± 1 SE (range)	CPUE ± 1 SE	Mean length (mm) ± 1 SE (range)	CPUE ± 1 SE	Mean length (mm) ± 1 SE (range)
Chinook salmon	0.052 ± 0.006	59.3 ± 1.1 (37–100)	0	0	0	0
Chinook/coho salmon	0	0	0.032 ± 0.010	68.3 ± 2.5 (35–81)	0.533 ± 0.092	80.8 ± 0.5 (61–114)
Chum salmon	0.148 ± 0.023	37.7 ± 0.2 (28–54)	1.065 ± 0.154	36.3 ± 0.1 (27–48)	0.405 ± 0.073	41.8 ± 0.3 (32–54)
Whitefishes	0.559 ± 0.074	44.1 ± 0.5 (15–210)	3.682 ± 0.549	40.6 ± 0.7 (21–510)	0.017 ± 0.009	29.7 ± 1.6 (23–35)
Arctic grayling	0.975 ± 0.150	52.9 ± 0.3 (29–350)	0.056 ± 0.012	70.8 ± 6.9 (37–201)	0	0
Inconnu	0.012 ± 0.003	98.5 ± 13.0 (35–360)	0	0	0	0
Longnose suckers	1.333 ± 0.161	56.5 ± 0.6 (12–400)	1.485 ± 0.197	65.6 ± 1.6 (22–460)	0	0
Slimy sculpin	0.002 ± 0.001	66.6 ± 6.9 (40–78)	0.006 ± 0.003	55.5 ± 9.0 (40–81)	0	0
Lethenteron spp.	0.036 ± 0.008	107.0 ± 2.5 (65–163)	0.176 ± 0.028	114.4 ± 1.8 (42–170)	0.001 ± 0.001	162
Arctic lamprey	0.001 ± 0.001	359.5 ± 18.0 (334–385)	0.003 ± 0.002	327.5 ± 15.9 (305–350)	0.002 ± 0.002	365.0 ± 10.6 (350–380)
Alaskan brook lamprey	0	0	0.003 ± 0.002	132.5 ± 5.3 (125–140)	0	0
Lake chub	0.042 ± 0.006	75.9 ± 2.8 (28–142)	1.042 ± 0.120	53.0 ± 0.7 (24–152)	0	0
Burbot	0.013 ± 0.003	188.2 ± 12.8 (35–325)	0.070 ± 0.021	301.9 ± 21.8 (60–450)	0.001 ± 0.001	155
Northern pike	0	0	0.001 ± 0.001	600	0	0

Table 2. Summary output from equation (2), which described seasonal temporal patterns, and if ΔAIC > 2, summary output from equation (3), which described daily temporal patterns. A list of significant environmental variables associated with catches from the best fit GAM (equation 4) is included, resulting from an all subsets model selection approach, for all four species/taxa captured in each location in the Yukon River at Eagle, AK. AIC and % deviance explained (% dev. exp) is provided for each equation and equivalent degrees of freedom (edf), F-statistic and a P-value is provided for each predictor (date, water temperature (Temp), and the Debris Index (DI)).

Species/taxa	Location	Equation	AIC	% dev. exp	Predictors	edf	F-statistic	P-value
Chum salmon	Left	Equation 2	167.2	67.8	Date	11.39	3.63	0.0011
	Middle Island	Equation 2	438.6	47.1	Date	8.45	7.08	<0.0001
	Right	Equation 2	179.1	1.37	Date	1.00	0.53	0.4680
Whitefishes	Left	Equation 2	363.1	64.1	Date	9.70	7.50	<0.0001
		Equation 4	356.1	68.2	Date	8.14	7.76	<0.0001
					DI	1.82	6.60	0.0027
	Middle Island	Equation 2	365.0	1.94	Date	1.00	2.95	0.0872
	Right	Equation 2	753.3	38.2	Date	11.36	6.97	<0.0001
		Equation 4	746.7	40.8	Date	10.45	5.56	<0.0001
					DI	1.71	5.94	0.0038
Longnose suckers	Left	Equation 2	466.5	63.8	Date	12.65	7.62	<0.0001
		Equation 4	427.6	79.3	Date	12.47	8.86	<0.0001
					DI	1.82	24.49	<0.0001
	Middle Island	Equation 2	787.0	23.9	Date	5.08	8.69	<0.0001
		Equation 4	777.7	26.6	Date	2.42	6.92	0.0001
					Temp	1.00	11.91	0.0006
					DI	1.00	8.98	0.0030
	Right	Equation 2	1023.6	46.3	Date	11.43	9.19	<0.0001
		Equation 3	1017.4	48.9	Date,Time	15.47	6.92	<0.0001
		Equation 4	994.5	53.9	Date	11.25	8.53	<0.0001
					DI	1.46	11.10	<0.0001
Arctic grayling	Left	Equation 2	334.6	77.1	Date	11.83	10.11	<0.0001
		Equation 4	327.5	80.6	Date	10.90	11.80	<0.0001
					DI	1.89	6.74	0.0022
	Middle Island	Equation 2	318.2	38.1	Date	9.28	4.62	<0.0001
		Equation 4	312.0	40.6	Date	6.23	7.67	<0.0001
					Temp	2.00	5.10	0.0068
	Right	Equation 2	727.6	72.5	Date	10.78	20.97	<0.0001
		Equation 3	709.5	79.2	Date,Time	17.36	17.62	<0.0001

Table 3. Summary output from equation (2), which described seasonal temporal patterns, and if ΔAIC > 2, summary output from equation (3), which described daily temporal patterns. A list of significant environmental variables associated with catches from the best fit GAM (equation 4) is included, resulting from an all subsets model selection approach, for all four species/taxa captured in each location in the Tanana River at Nenana, AK. AIC and % deviance explained (% dev. exp) is provided for each equation and equivalent degrees of freedom (edf), F-statistic and a P-value is provided for each predictor (date, water temperature (Temp), turbidity, and the Debris Index (DI)).

Species/taxa	Location	Model	AIC	% dev. exp	Predictors	edf	F-statistic	P-value
Chum salmon	Left	Equation 2	240.9	66.9	Date	7.10	14.95	<0.0001
	Mid-channel	Equation 2	248.7	50.4	Date	6.47	5.22	0.0002
	Right	Equation 2	400.2	75.6	Date	10.08	16.69	<0.0001
		Equation 4	397.0	77.2	Date	8.79	17.18	<0.0001
					Temp	1.74	6.03	0.0042
Chinook/coho salmon	Mid-channel	Equation 2	263.8	58.5	Date	5.21	8.89	<0.0001
Whitefishes	Left	Equation 2	558.1	33.4	Date	7.82	7.03	<0.0001
	Right	Equation 2	936.2	65.9	Date	12.67	22.37	<0.0001
		Equation 4	917.7	70.5	Date	10.87	15.02	<0.0001
					Temp	1.92	8.00	0.0005
					DI	1.00	13.23	0.0004
					Turbidity	1.93	5.21	0.0064
Longnose sucker	Left	Equation 2	506.9	18.1	Date	1.00	30.57	<0.0001
		Equation 3	485.3	45.4	Date,Time	19.96	3.85	<0.0001
		Equation 4	469.9	48.0	Date	12.63	4.17	<0.0001
					DI	1.95	6.00	0.0031
					Turbidity	1.00	3.95	0.0486
	Right	Equation 2	881.5	31.4	Date	11.84	4.84	<0.0001
		Equation 4	868.3	37.9	Date	10.98	5.21	<0.0001
					Temp	2.00	3.52	0.0315
					Turbidity	2.00	3.35	0.0371
Lake chub	Left	Equation 2	637.8	1.48	Date	1.00	2.06	0.1530
		Equation 4	630.7	4.9	Date	1.00	0.02	0.8850
					Temp	1.00	5.62	0.0188
	Right	Equation 2	605.5	30.1	Date	11.05	3.27	0.0002
		Equation 4	595.5	34.0	Date	9.43	2.92	0.0013
					Temp	1.76	8.07	0.0006

Figure 1. Map of Yukon and Tanana rivers.


N
Yukon
Territory
Dawson
White River
600 Kilometers

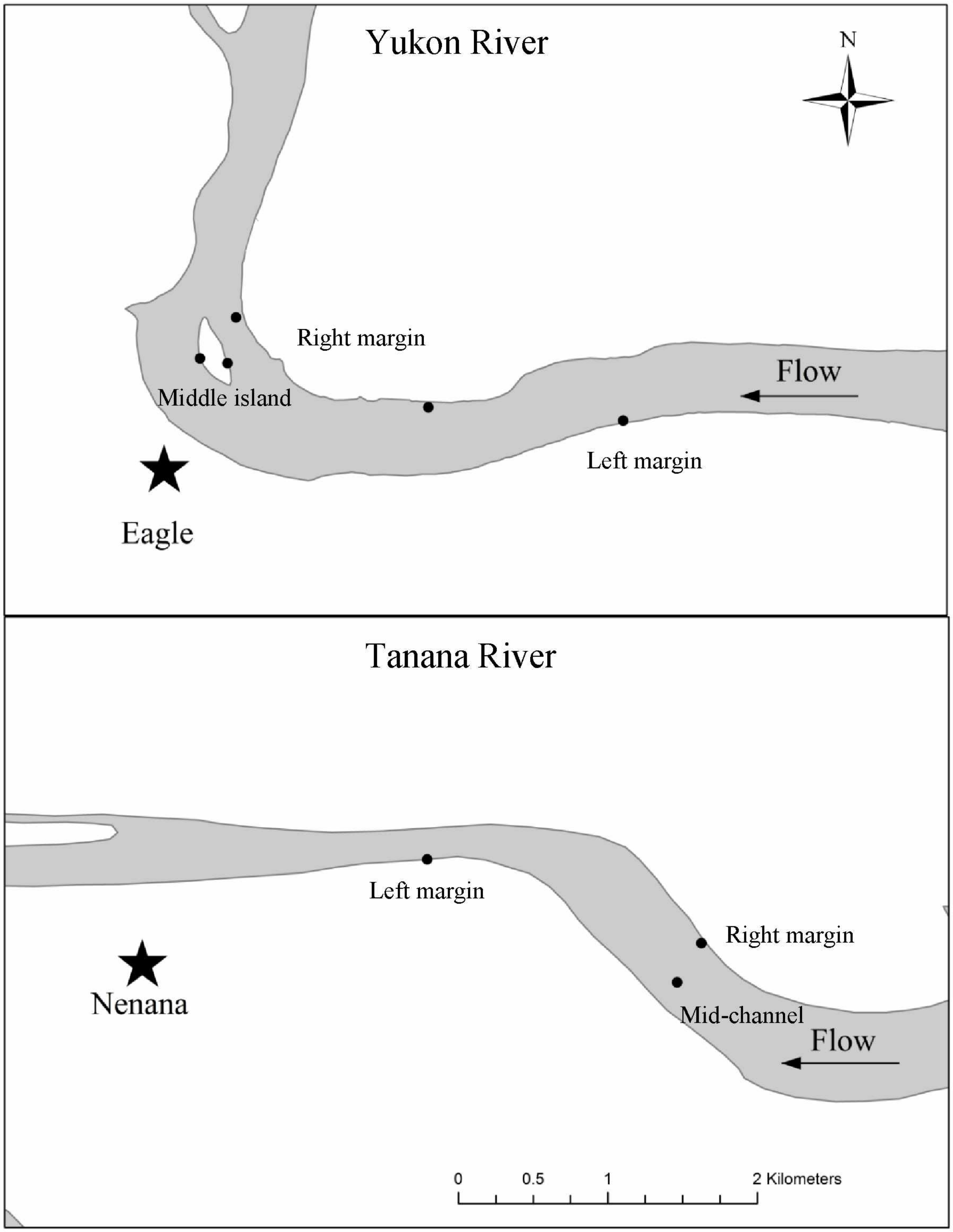

Figure 2. Sampling sites in the Yukon River at Eagle, AK and Tanana River at Nenana, AK.

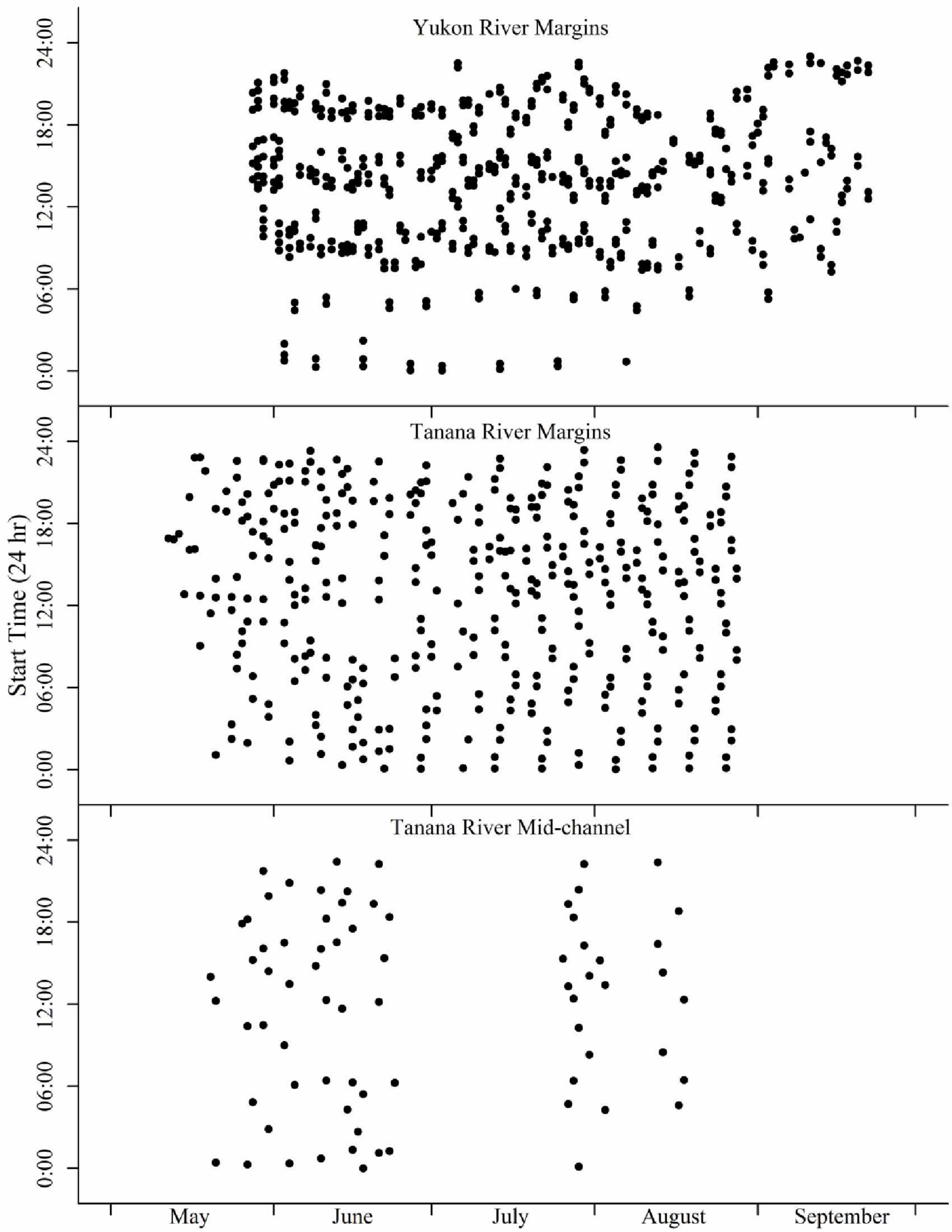

Figure 3. Start time for each fyke net set in the Yukon River (top) and Tanana River (middle) and incline plane trap set in the Tanana River (bottom).

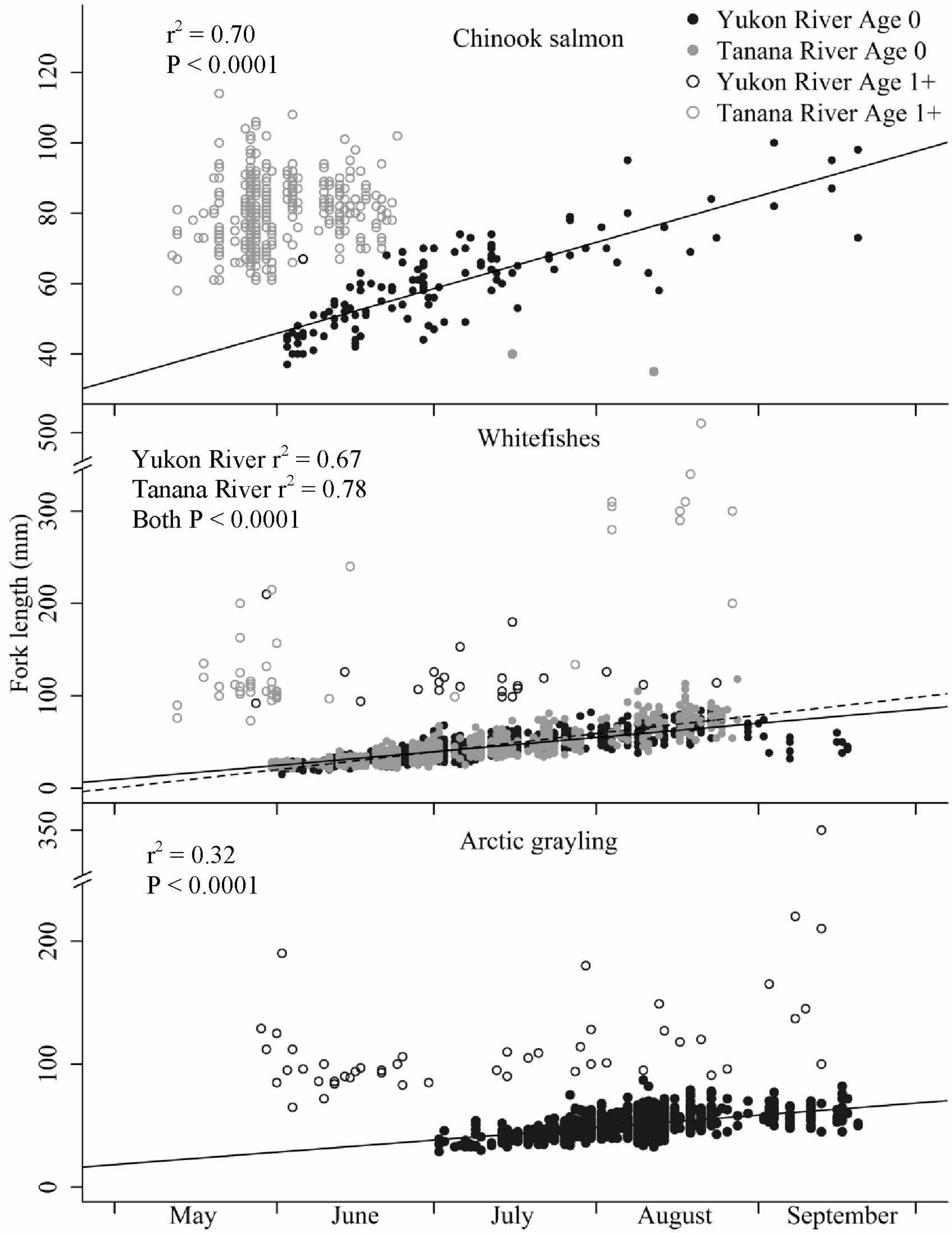

Figure 4. Fork length (mm) of Chinook salmon and Arctic grayling captured in the Yukon River and whitefishes captured in the Yukon and Tanana rivers. Solid dots represent presumed age 0 fishes and hollow dots represent presumed age 1+ fish. Only age 0 fishes were included in the linear model represented by solid (Yukon River) and dashed (Tanana River) lines.

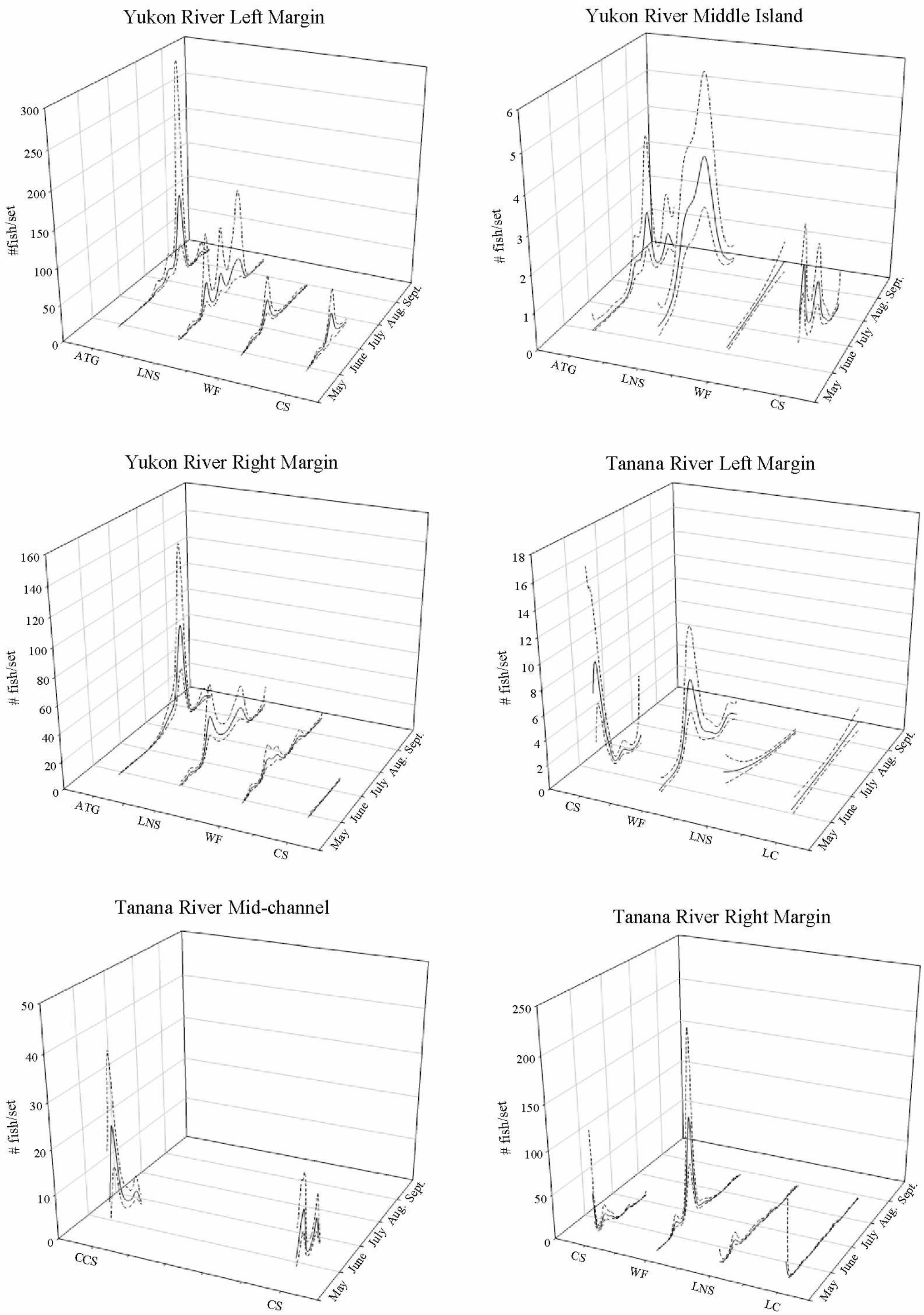

Figure 5. GAM smoother trendline (solid line) encompassed by a 95% confidence interval (dashed line) describing trends in catches for each species/taxa (Arctic grayling (ATG), longnose suckers (LNS), whitefishes (WF), chum salmon (CS), lake chubs (LC), and Chinook/coho salmon (CCS) in each location in the Yukon and Tanana rivers.

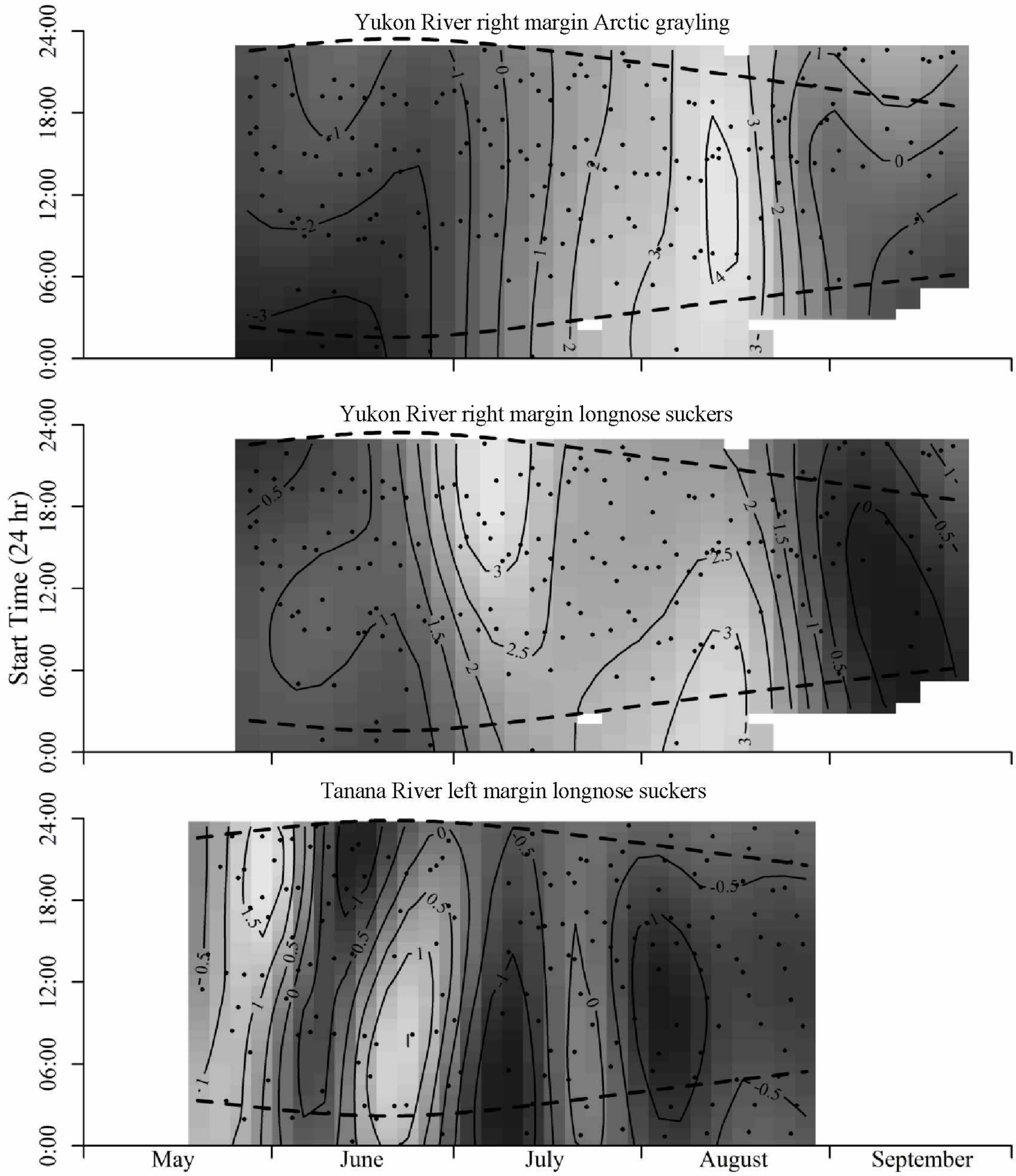

Figure 6. Contour plot of catches of Arctic grayling (top) and longnose suckers (middle) on the right margin of the Yukon River at Eagle, AK and longnose suckers (bottom) on the left margin of the Tanana River at Nenana, AK with interaction between time of day and day of year. Light gray represents high catches while dark gray represents low catches. Black contour lines represent deviations from the overall mean on the log-scale (anomalies). Dots represent individual fyke net sets and dashed lines represent times of sunrise and sunset.

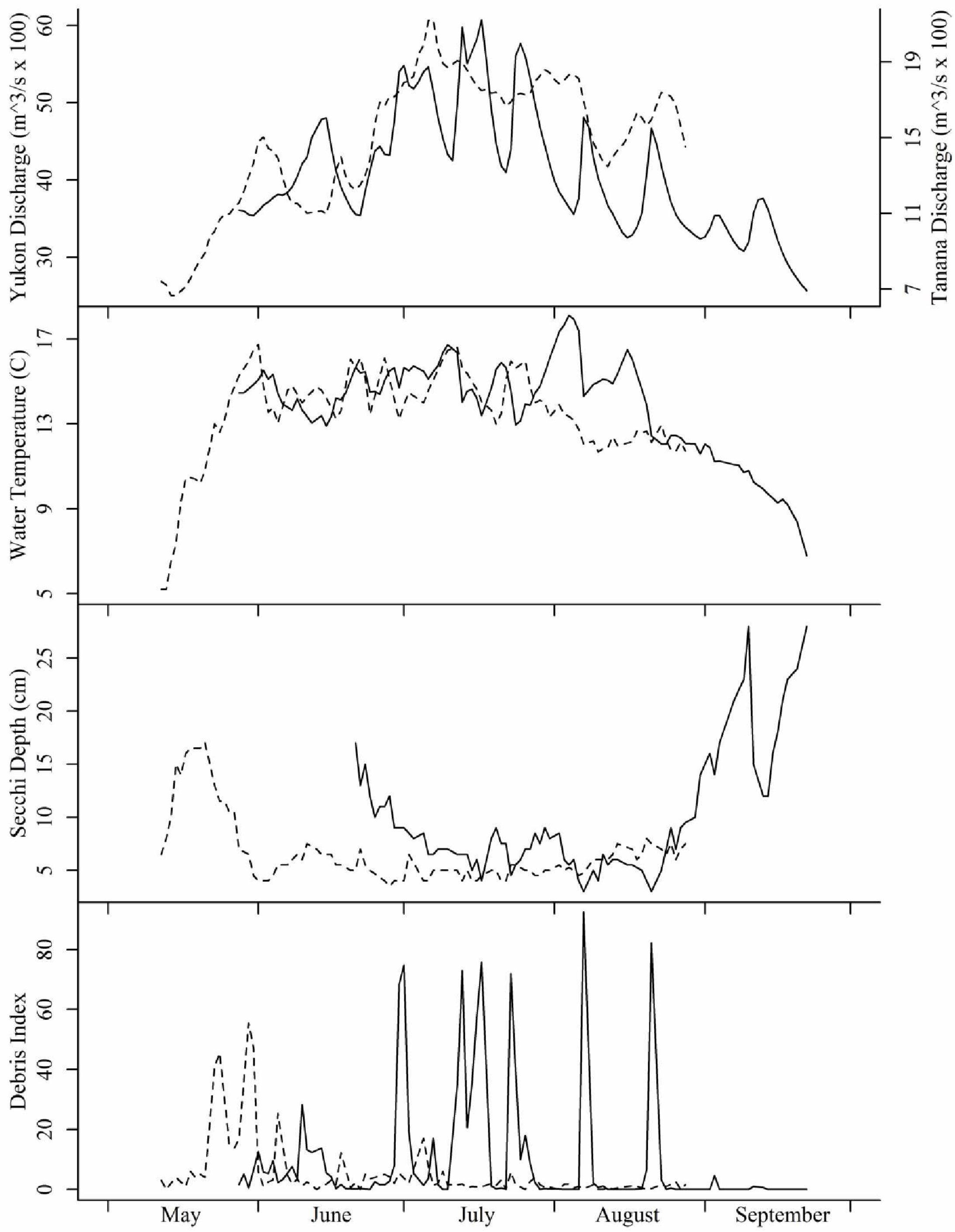

Figure 7. Discharge ($m^3 \cdot s^{-1}$) x 100, daily mean water temperature (°C), secchi depth (cm), and daily mean of the Debris Index of the Yukon River (solid line) at Eagle, AK and Tanana River (dashed line) at Nenana, AK.

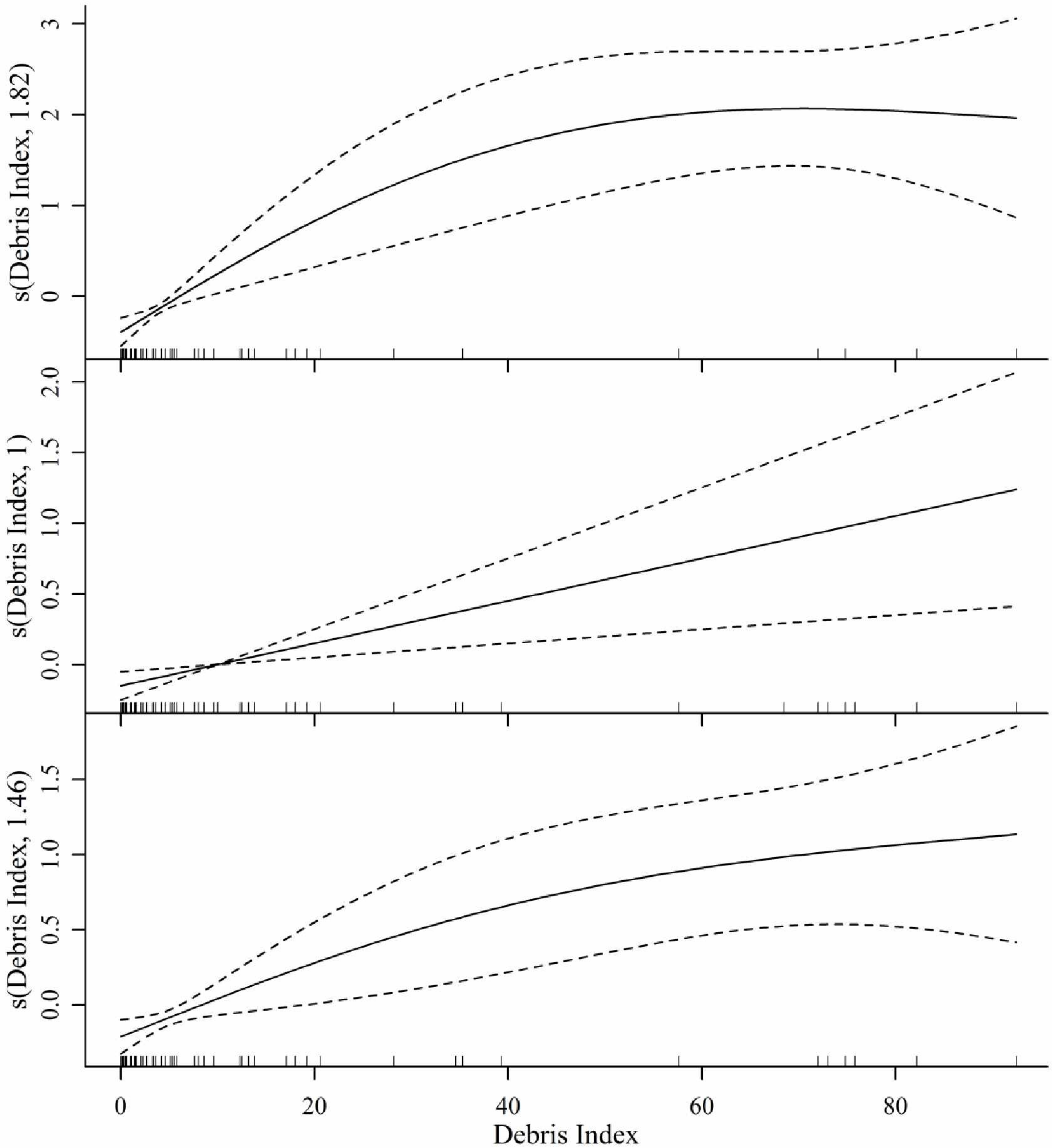

Figure 8. Estimated effect of the Debris Index on catches of longnose suckers (solid line) encompassed by a 95% confidence interval (dotted lines) on the left margin (top), middle island (middle) and right margin (bottom) of the Yukon River at Eagle, AK. The y-axis represents the effect of the Debris Index on catches, were s is a smoother term and the number in parentheses is the equivalent degrees of freedom (edf). Ticks in the x-axis represent observed values of the Debris Index.

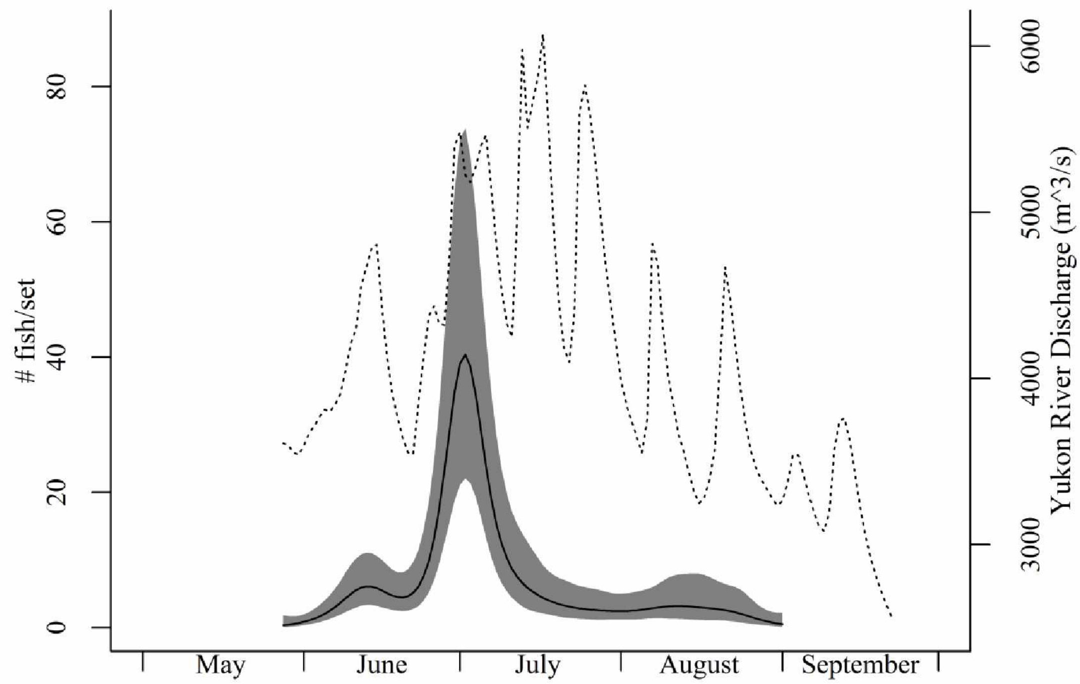

Figure 9. GAM smoother trendline (solid line) encompassed by a 95% confidence interval (shading) describing trends in catches for whitefishes on the left margin of the Yukon River at Eagle, AK. Plotted on the secondary axis is discharge ($m^3 \cdot s^{-1}$) of the Yukon River (dotted line).

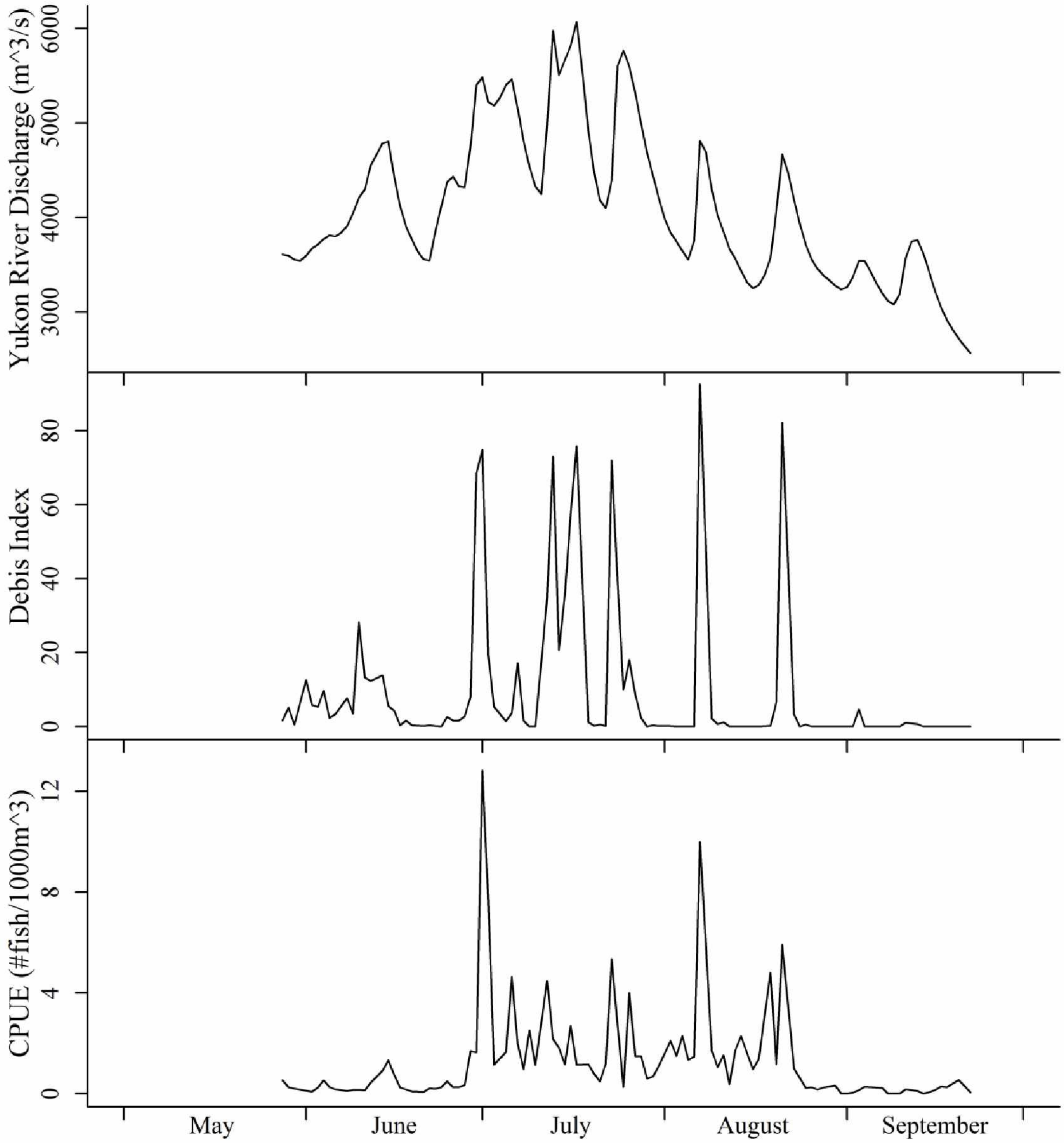

Figure 10. Yukon River discharge ($m^3 \cdot s^{-1}$), daily mean of the Debris Index, and daily mean CPUE (#fish$\cdot$(1,000 m^{-3}) of longnose suckers at Eagle, AK.